



# An Open Access Wireless Market

*Supporting Competition, Public Safety, and Universal Service*

Peter Cramton

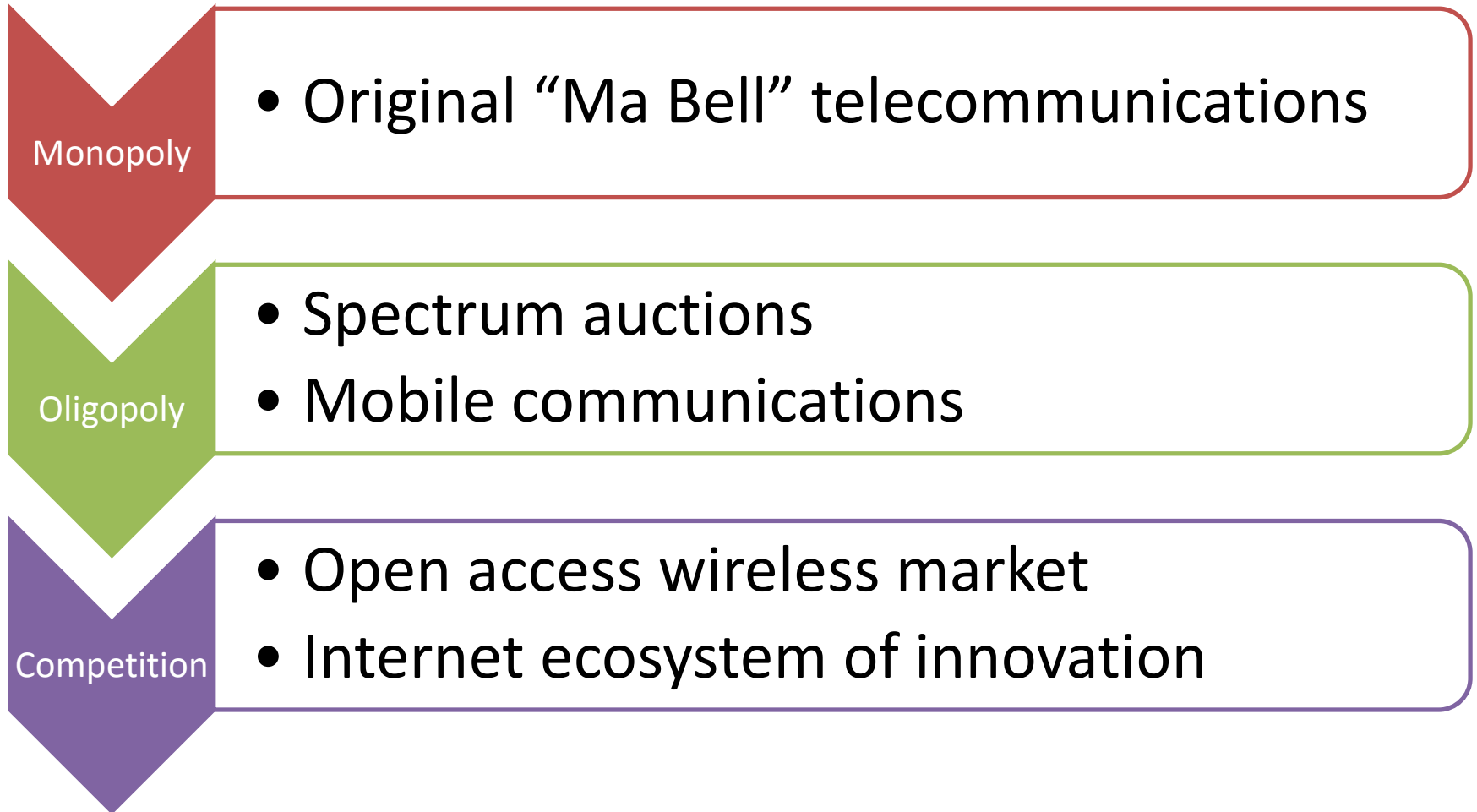
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*Trinity College Dublin*

2 March 2016

# From monopoly to vibrant competition



# The time is right

- Global technology standard: LTE
  - Ability to disaggregate and reassign network resources
- Flexibility as an enabler
  - Handsets now support about 40 bands
  - Basestation now software defined
- Demand heterogeneity
  - Expanding applications: Internet of Things,...
- Benefits of sharing scarce resources
  - Towers, spectrum, network

# Market objectives

- Efficiency
- Transparency
- Simplicity
- Fairness

*Draw on best practice from existing time and locational markets*

# Key market principle: open access

- Network is open to all
  - Nondiscriminatory terms
  - Network capacity cannot be withheld
- ⇒ Efficient congestion pricing
- Basis for restructured electricity markets in US, Europe, ...

Wholesale  
market

# Mobile networks

Open access  
network  
(ISO)

Proprietary  
network 1  
(MNO<sub>1</sub>)

Proprietary  
network 2  
(MNO<sub>2</sub>)

## Service providers

Mobile virtual  
network operator  
(MVNO)

MNO<sub>1</sub>

MNO<sub>2</sub>

## Users/devices

A

B

C

D

E

F

G

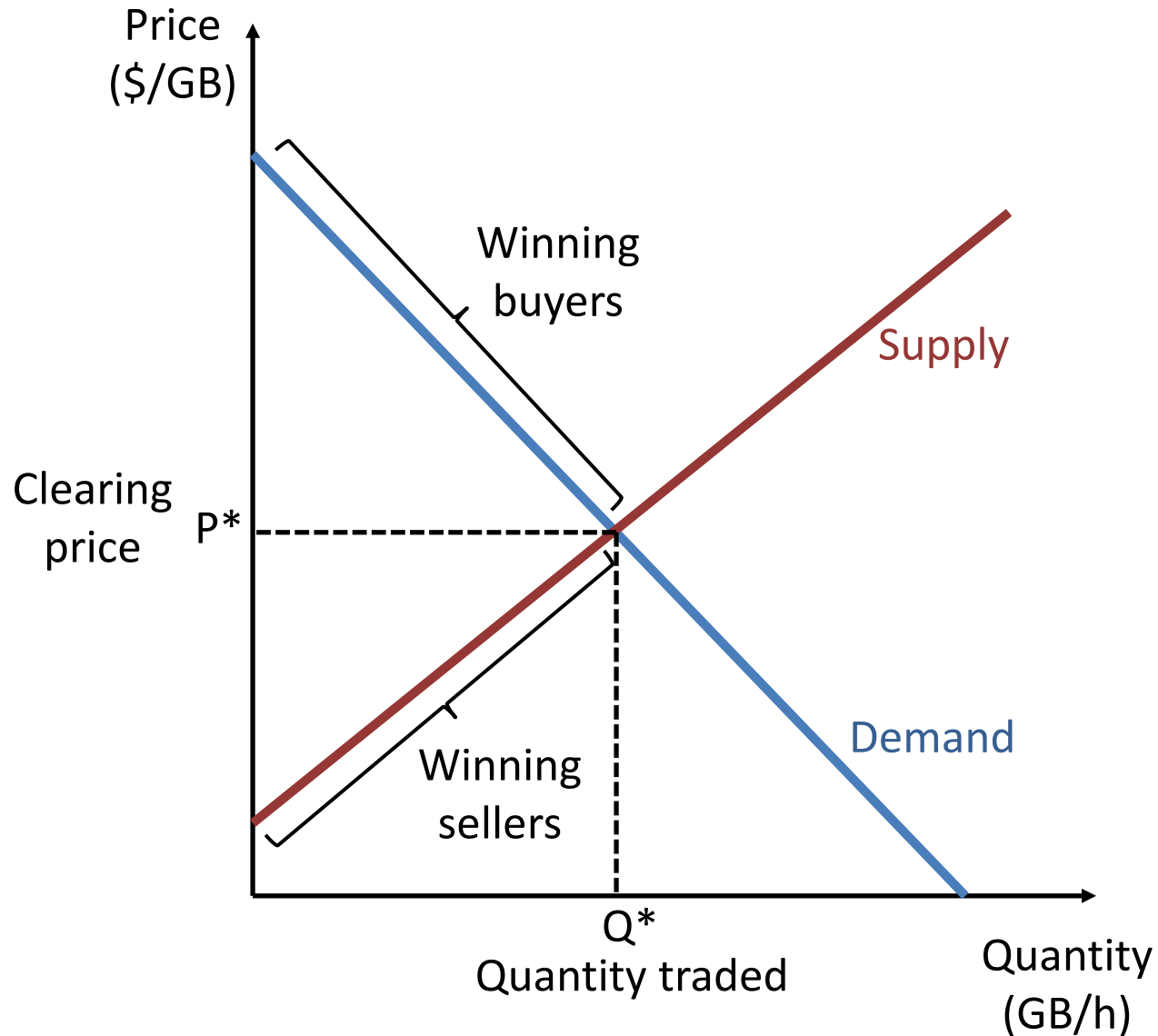
Retail  
market

*Same market model as electricity  
successfully operating for two decades*

# Product design

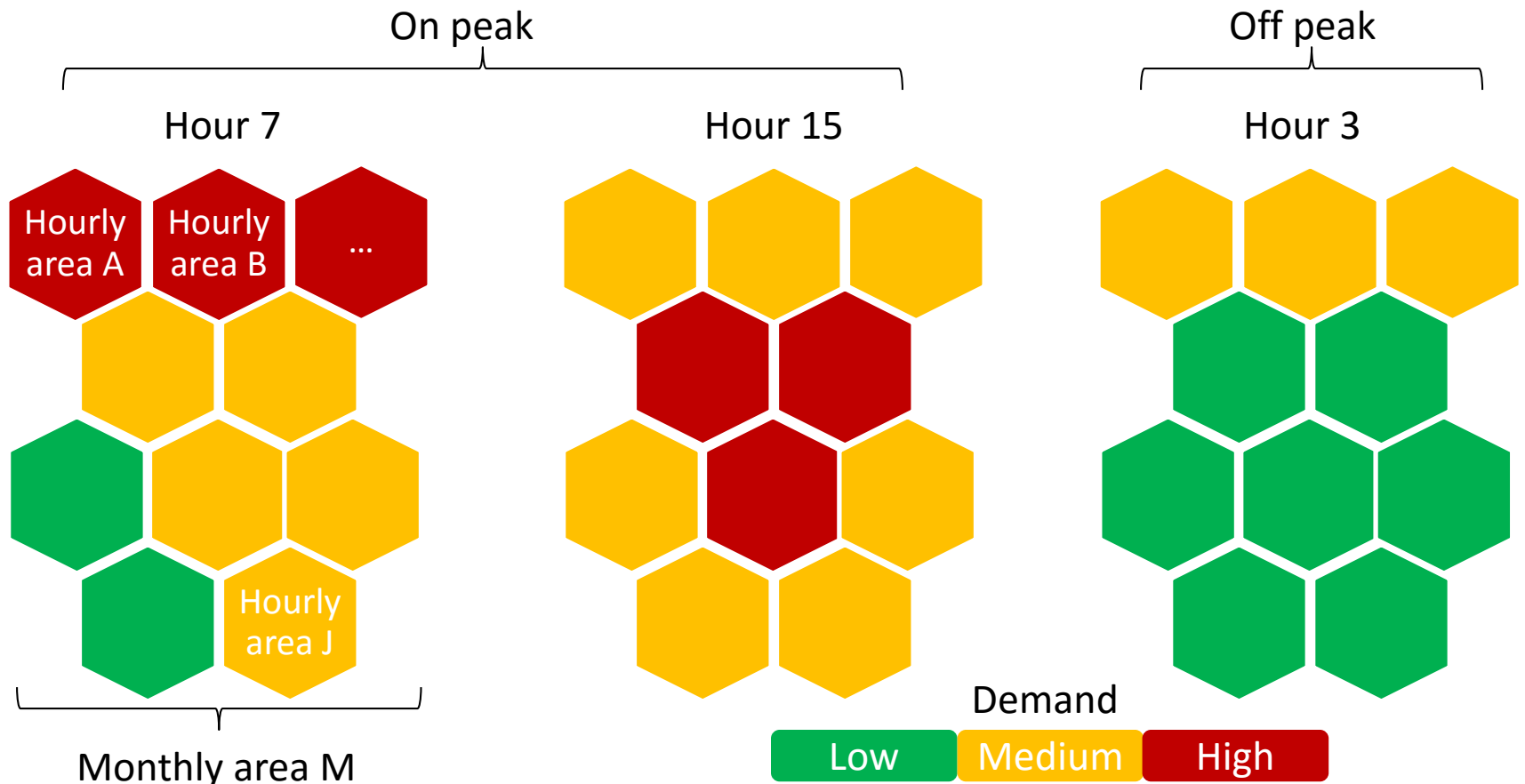
- Product should be directly valued by consumer
  - Network throughput at particular location and time interval
  - A market for throughput not spectrum
  - Energy (MWh) in an electricity market
- Aggregation in both time and location to simplify and improve liquidity
  - Example: Particular cell over one hour (GB/h)

# All markets use single-price auction



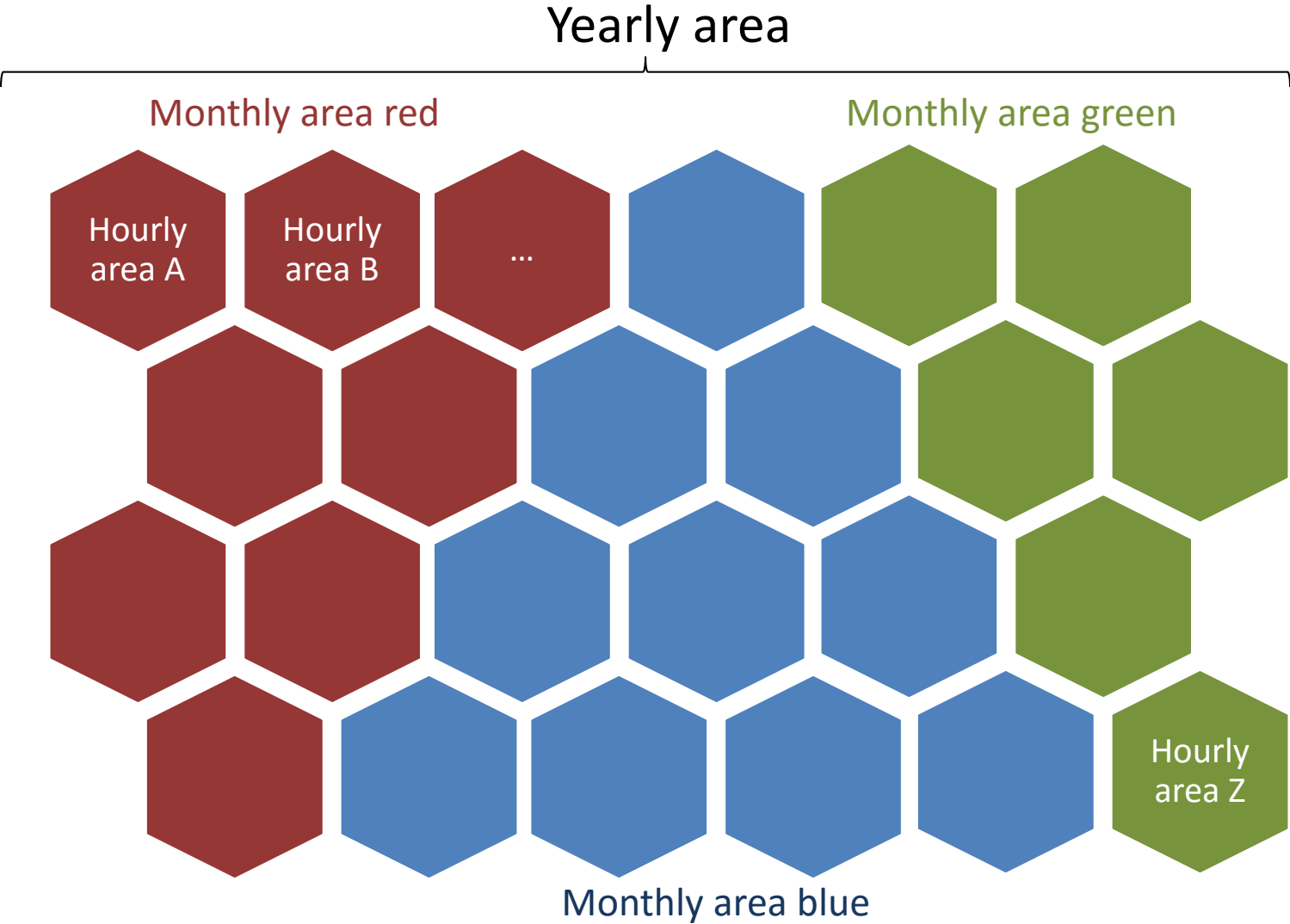


# Multiple opportunities to trade: Yearly, monthly, hourly



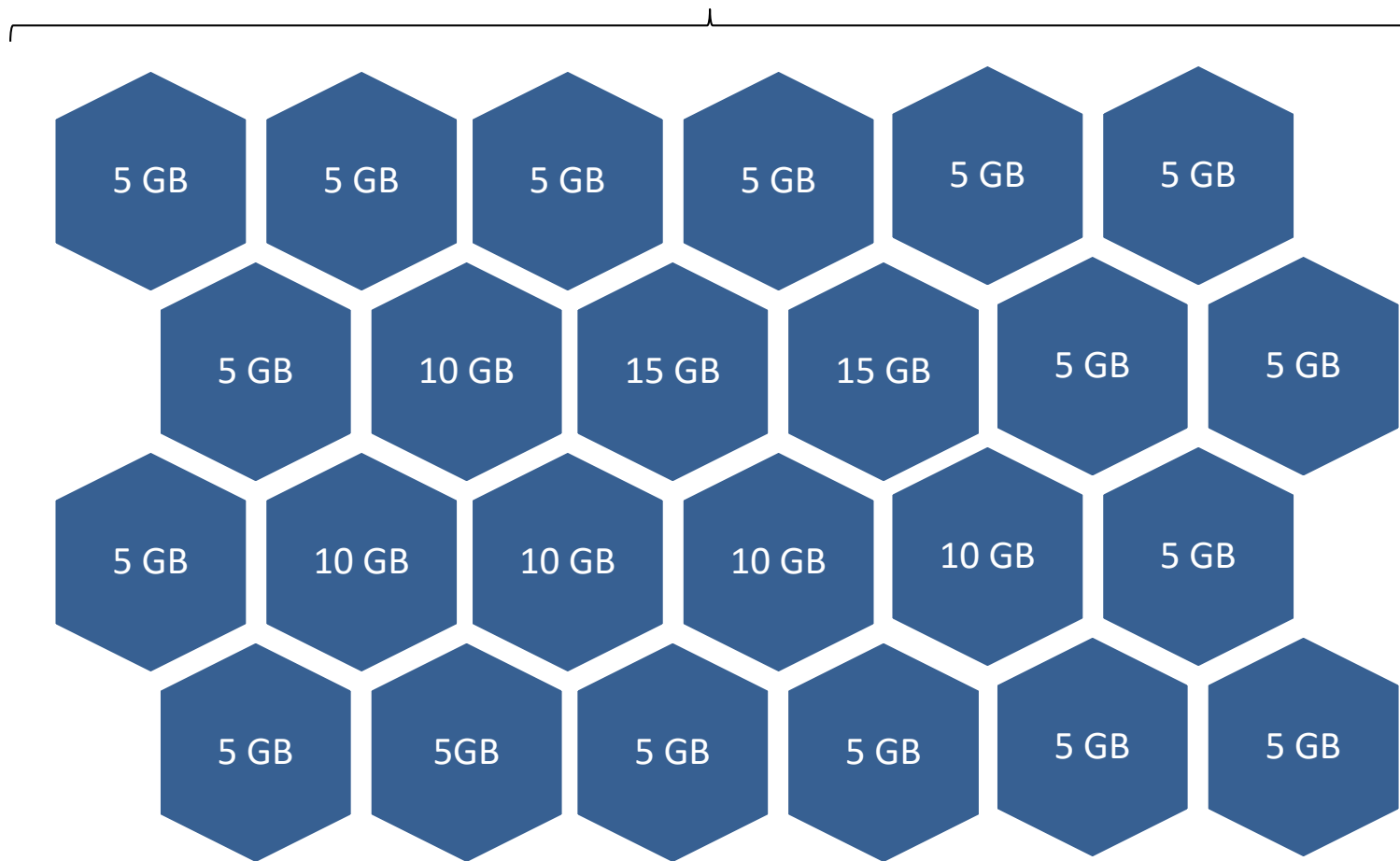
*Yearly aggregates monthly aggregates hourly in time and location*

# Forward market area aggregation



# Service provider estimates demand and stages purchase in three markets

Yearly auction = buy 165 GB per hour, for every peak hour in the year, in the yearly area

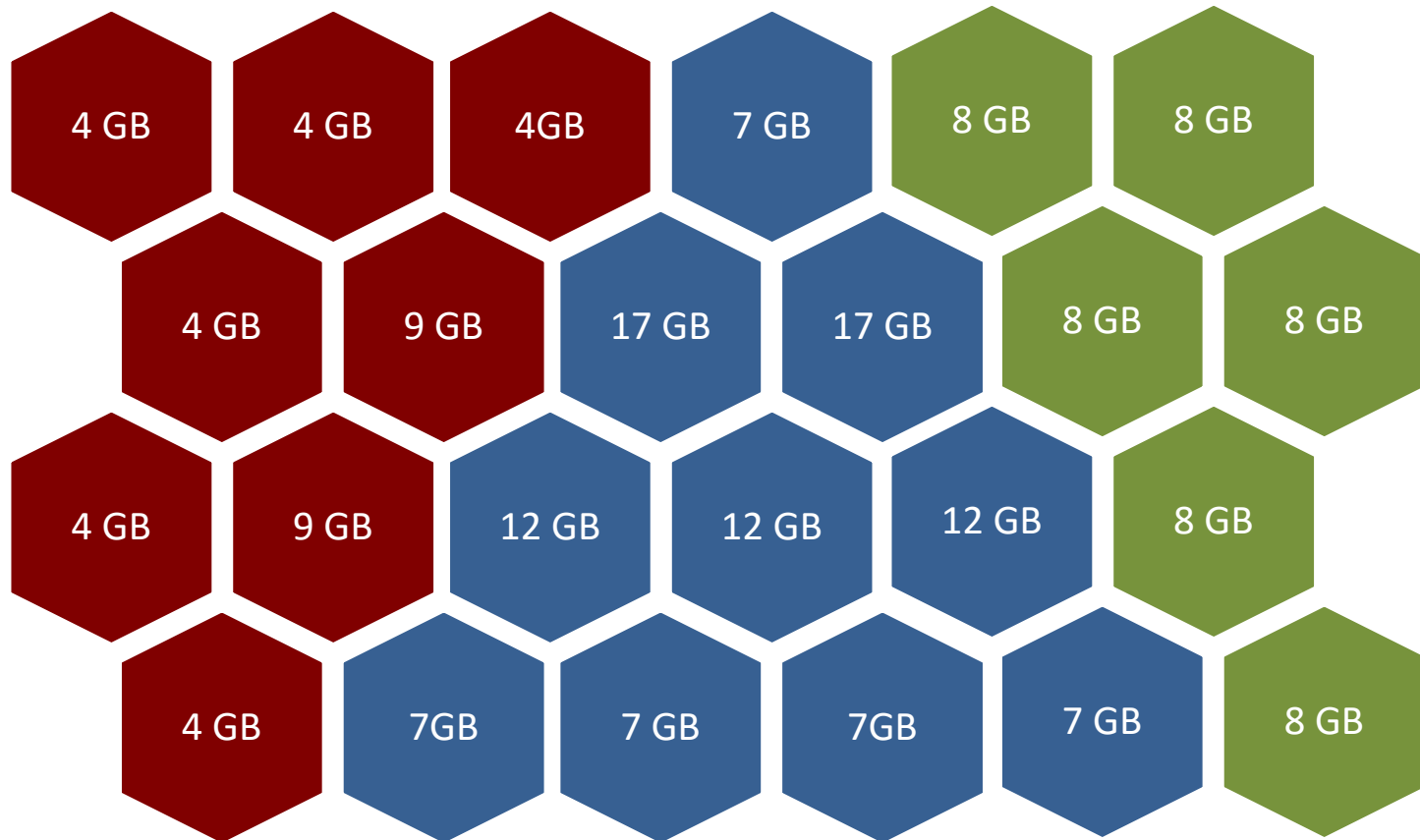


# Refine estimate and make adjustment in monthly market

Yearly auction = buy 165 GB per hour, for every peak hour in the year, in the yearly area

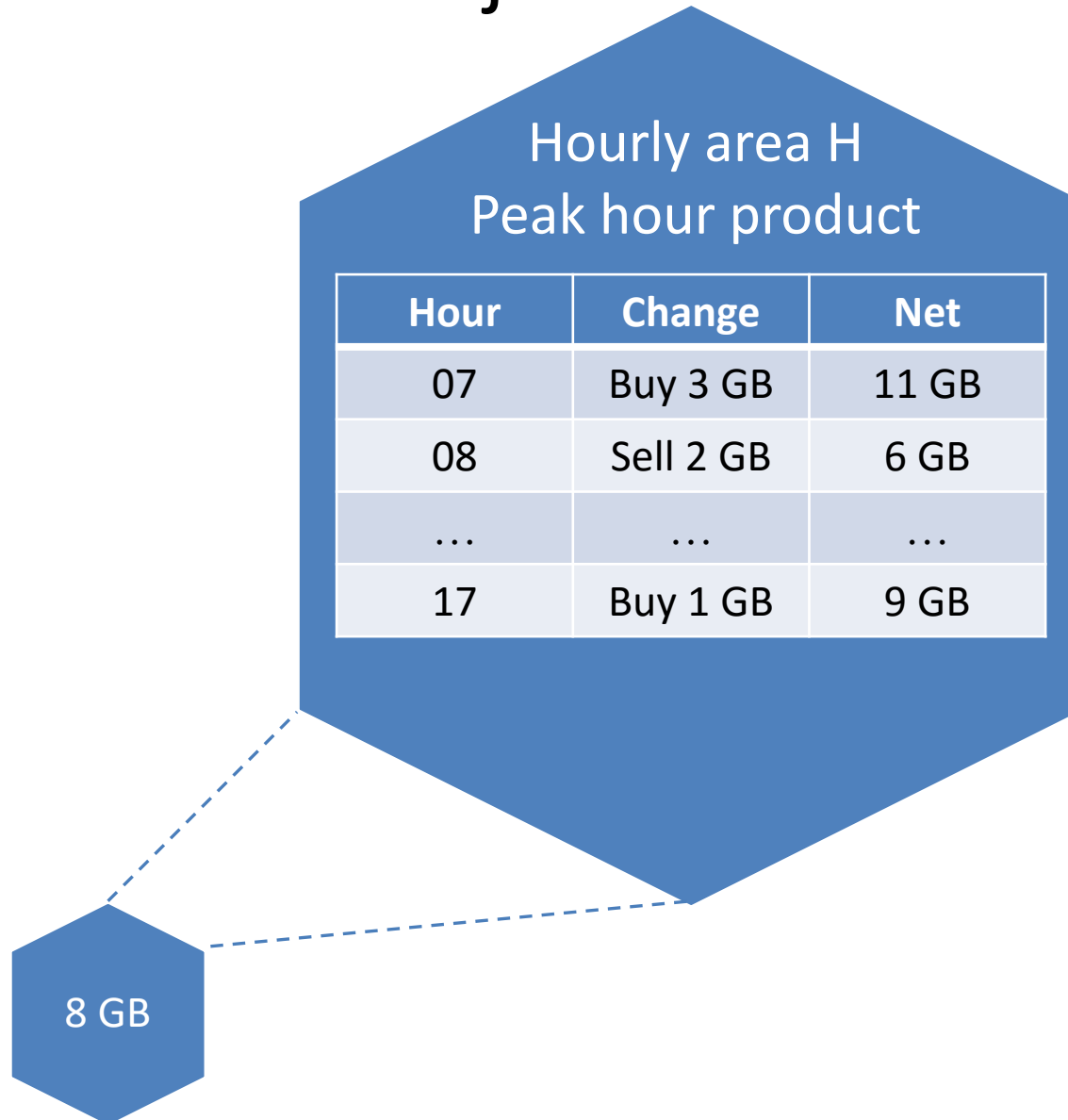
Monthly auction = sell 8 GB per hour, for every peak hour in the month, in the red area

Monthly auction = buy 15 GB per hour, for every peak hour in the month, in the green area



Monthly auction = buy 20 GB per hour, for every peak hour in the month, for the blue area

# Finalize estimate one hour ahead and make final adjustment to demand

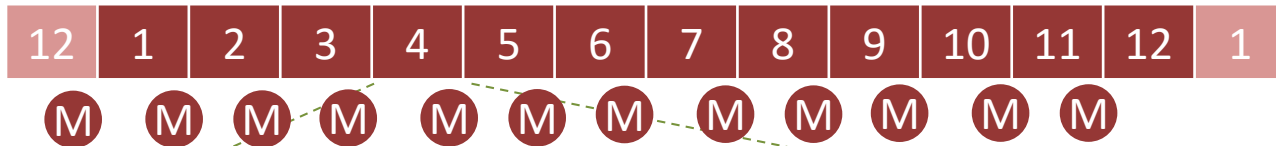


# Product and auction hierarchy



Y

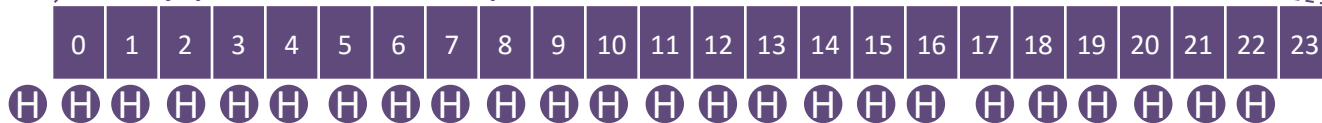
Monthly product for 2017



Day of month in April 2017



Hourly product for 5 April 2017



Y = Auction conducted in December for yearly products

M = Auction conducted last week of each month for monthly products

H = Auction conducted every hour for hourly products

## Sequence of auctions

Yearly  
auction

Monthly  
auctions

Hour  
ahead  
auction

Hourly  
realization

## Example

Buy 8 GB  
in each hour

April:  
Sell 1 GB  
7 GB net

April 5, hour 15:  
Buy 3 GB  
10 GB net

April 5, hour 15:  
-1 GB deviation  
9 GB demand

- Three opportunities to trade
  - Reduces risk of service provider
  - Facilitates planning of service provider
  - Provides price transparency
  - Mitigates market power

# Prototype auction platform

- To illustrate market
- Demonstrate proof of concept



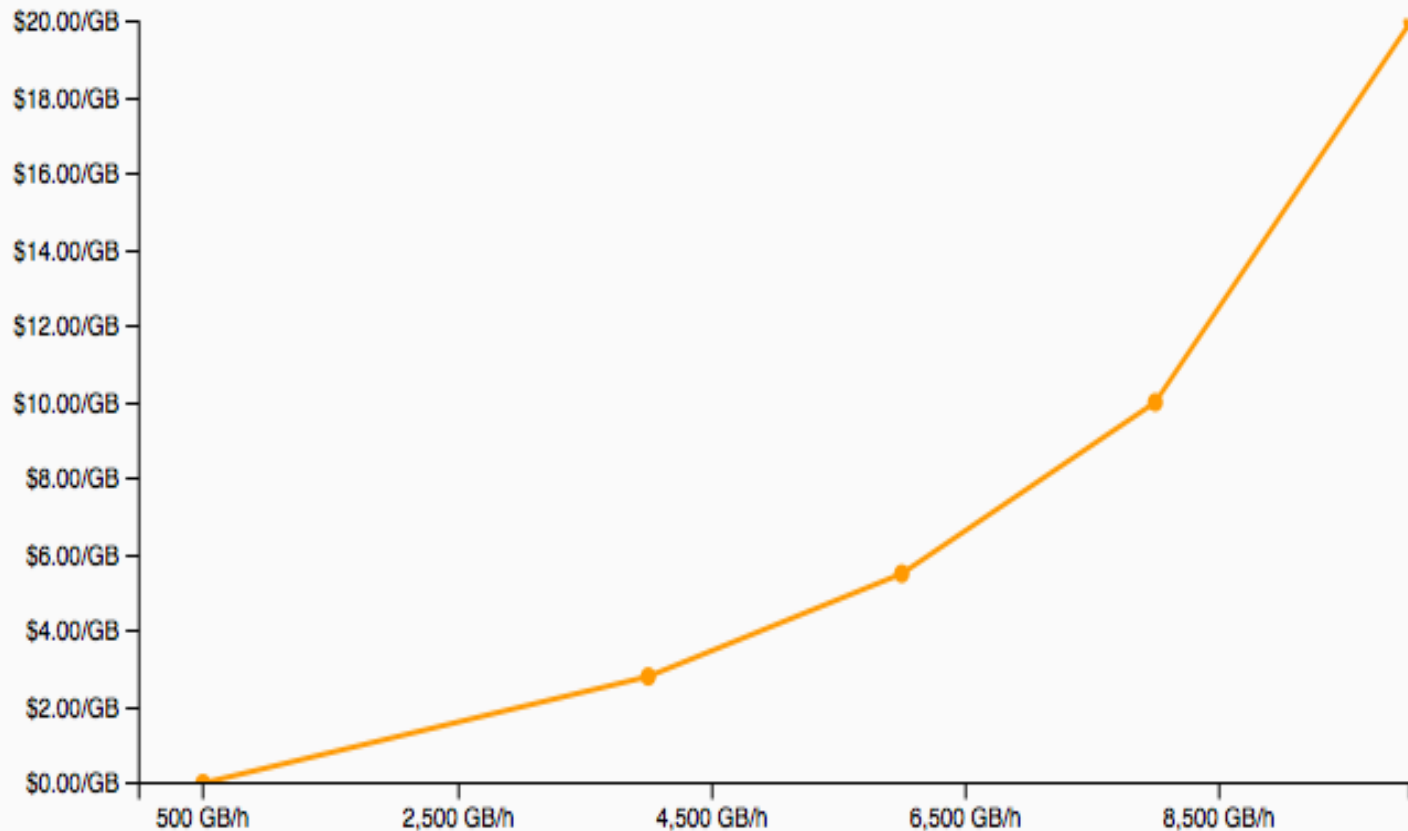
# Auction design

- Uniform-price auction for each product
- Preferences expressed as piecewise-linear strictly-decreasing demand curves
  - Consistent with underlying preferences
  - Unique clearing prices and quantities
- Yearly and monthly auctions: simultaneous ascending clock
- Hourly auction: sealed bid

# Current Published Supply Curve for Manhattan (Peak)

Select a product to view its supply curve calculated from the relative supply curve currently in the system.

Manhattan (Peak) ▾



# Sample demand for bidder

## Manhattan (peak) monthly

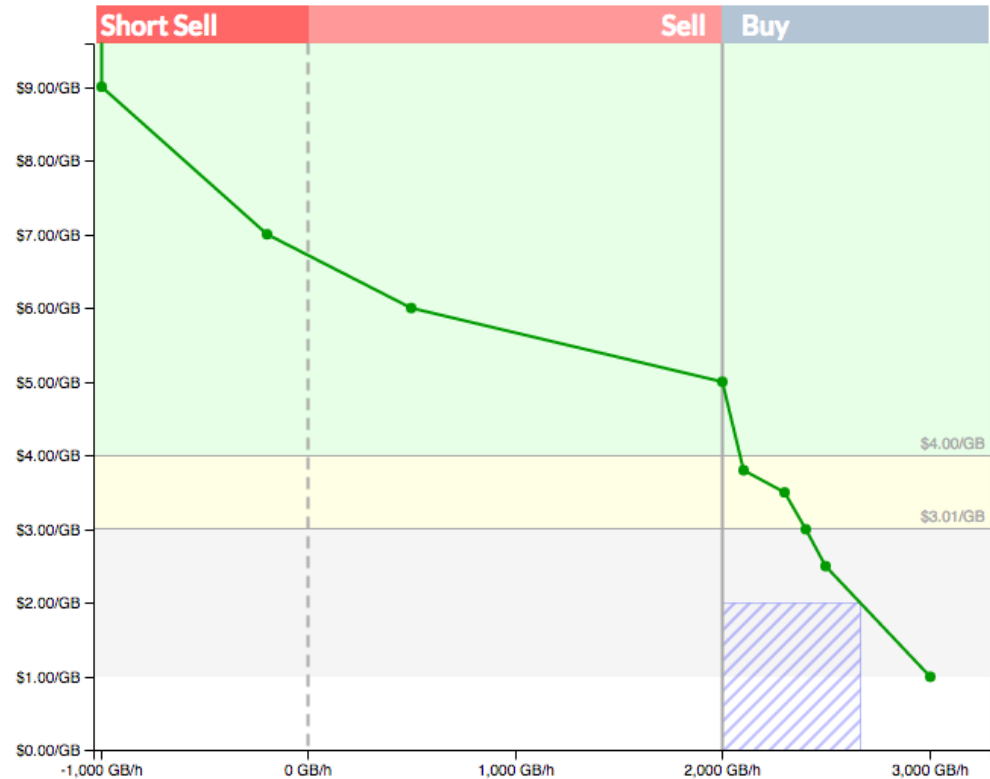
Manhattan (Peak)

At \$  /GB hold  GB/h

Your Forward Position: 2,000,000 GB/h

Published Maximum Supply: 10,000,000 GB/h

	Price	Quantity	Change in Quantity	Commitment (180 hours)
<i>Future Rounds</i>				
✉	\$9.00/GB <input type="button" value="🗑️"/>	<u>-1,000,000 GB/h</u> <input type="button" value="✎"/>	-3,000,000 GB/h	-\$4,860,000
✉	\$7.00/GB <input type="button" value="🗑️"/>	<u>-200,000 GB/h</u> <input type="button" value="✎"/>	-2,200,000 GB/h	-\$2,772,000
✉	\$6.00/GB <input type="button" value="🗑️"/>	<u>500,000 GB/h</u> <input type="button" value="✎"/>	-1,500,000 GB/h	-\$1,620,000
✉	<u>\$5.00/GB</u> <input type="button" value="✎"/>	2,000,000 GB/h	0.000 GB/h	\$0
<i>Current Round</i>				
	\$4.00/GB	2,083,333 GB/h	83,333 GB/h	\$60,000
✉*	\$3.80/GB <input type="button" value="🗑️"/>	<u>2,100,000 GB/h</u> <input type="button" value="✎"/>	100,000 GB/h	\$68,400
✉*	\$3.50/GB <input type="button" value="🗑️"/>	<u>2,300,000 GB/h</u> <input type="button" value="✎"/>	300,000 GB/h	\$189,000
<i>Past Rounds</i>				
	\$3.00/GB	2,400,000 GB/h	400,000 GB/h	\$216,000
✉🔒	\$2.50/GB	2,500,000 GB/h	500,000 GB/h	\$225,000
⬆️	\$2.00/GB	2,666,667 GB/h	666,667 GB/h	\$240,000
<i>Price Floor</i>				
✉🔒	\$1.00/GB	3,000,000 GB/h	1,000,000 GB/h	\$180,000

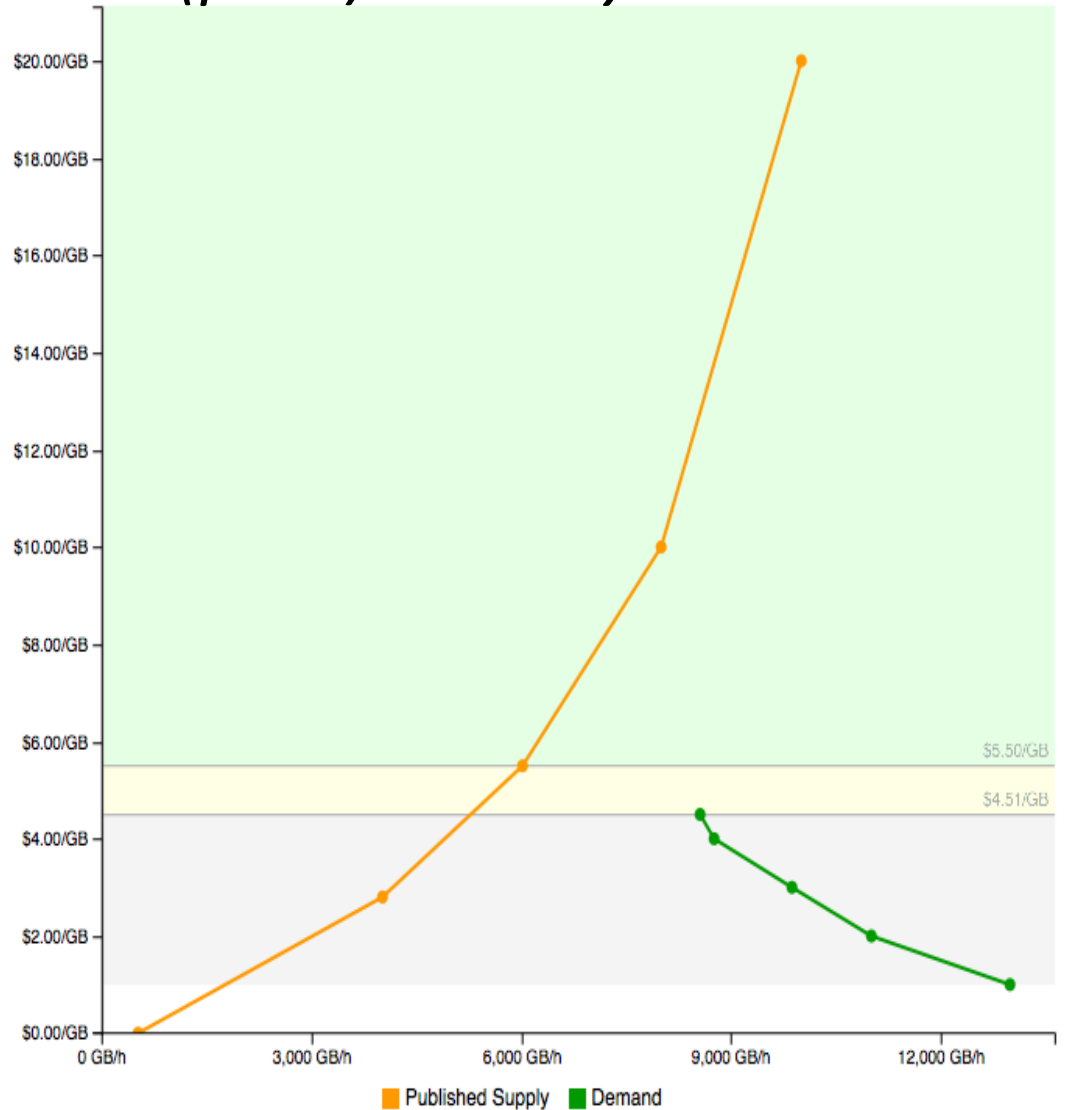


# Bidder's screen of supply and demand

## *Manhattan (peak) monthly*

### Manhattan (Peak)

Product has not yet cleared.	
Supply at end of round	5,259 GB/h
Demand	8,563 GB/h (33.04%)



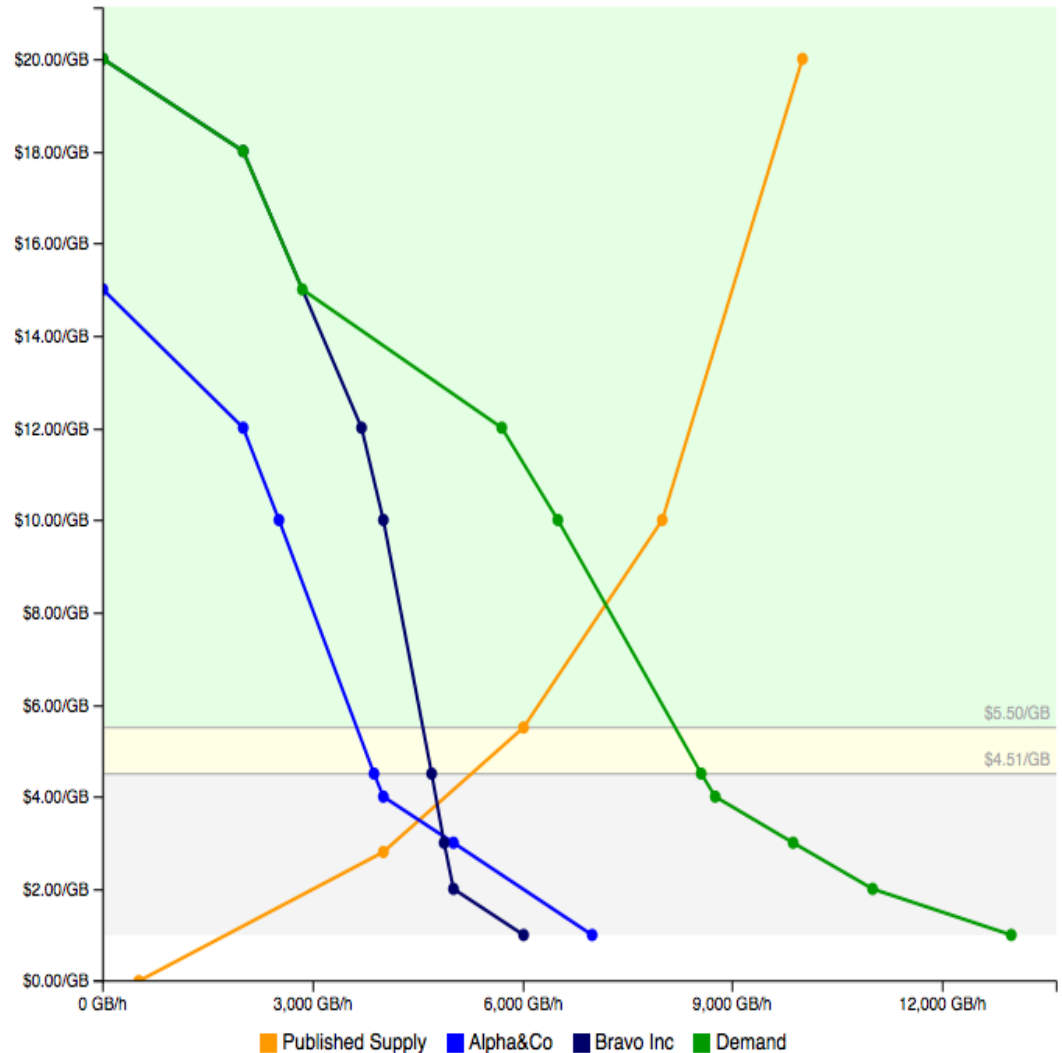
# Auctioneer's screen of supply and demand

## Manhattan (peak) monthly

### Manhattan (Peak)

Product has not yet cleared.	
Projected clearing price based on proxy bids	
Clearing Price	\$8.17/GB
Clearing Quantity	7,187 GB/h
Total Sold	\$58,718
Number of Buyers	2
Number of Sellers	0

Show Bidder Demand Curves



# Addressing hourly deviations between actual and purchased demand

- Neither system operator nor service provider can *control* demand perfectly to assure quantity consumed = quantity won
- Deviations are inevitable
- Final settlement should motivate service providers to limit deviations

# Hourly settlement for deviations

- $p_{hk}$  = price in hour  $h$  in area  $k$  that balances as-bid demand with estimated supply
- $q_{ihk}$  = total quantity bought by bidder  $i$  in hour  $h$  in hourly area  $k$   
(includes yearly, monthly, and hourly net purchases)
- $Q_{ihk}$  = actual quantity consumed by bidder  $i$  in hour  $h$  in hourly area  $k$
- $D_{ihk} = Q_{ihk} - q_{ihk}$  = deviation between actual quantity consumed and quantity bought
- *Tolerance* = percentage tolerance band (e.g., 10%);  
no penalty if deviation is within *Tolerance*
- *Penalty Factor* = a factor that is applied to square deviations above *Tolerance*
- Adjustment for deviations in the real-time market is  
 $Adjustment_{ihk} = p_{hk} \times D_{ihk} + Penalty_{ihk}$  where

$$Penalty_{ihk} = \begin{cases} 0 & \text{if } \frac{|D_{ihk}|}{q_{ihk}} \leq Tolerance \\ Penalty\ Factor \times p_{hk} \times D_{ihk}^2 & \text{if } \frac{|D_{ihk}|}{q_{ihk}} > Tolerance \end{cases}$$

*Standard efficient settlement if deviation is within Tolerance;  
penalty based on squared deviation outside of Tolerance to  
induce best estimate and control of demand to match winnings*

# Likely implementations

- Singapore (competition)
  - 60 MHz set aside for new entrant; auction in 2016
- Mexico (competition)
  - 90 MHz of 700 MHz set aside for open access
  - RFP to select implementer in 2016
- United States (public safety)
  - 20 MHz of 700 MHz set aside + \$7 billion
  - RFP to select implementer in 2016
- Australia (unsold spectrum)
  - 20 MHz of 700 MHz unsold; could be used for open access
- European Union (merger remedy; e.g. UK: Three & O2)
  - Proposed mergers leading from 4 to 3 carriers
  - Merged entity allocates portion of network to open access



# Merger remedy: set aside portion of capacity to open access network

- Similar to recent 4-to-3 merger remedies in Germany and Ireland, but much more responsive to changing market
  - Competitive forces determine identity and number of services providers
  - Assignment and prices determined to maximize gains from trade in open competitive process
  - Assignment and prices respond to changing market
  - Market evolves with environment
  - Merged entity receives competitive market value for network resource, and ongoing interest in success of service providers
- Similar to electricity merger remedy: auction portion of generation as “Virtual Power Plants” e.g. EDF 2001-2012

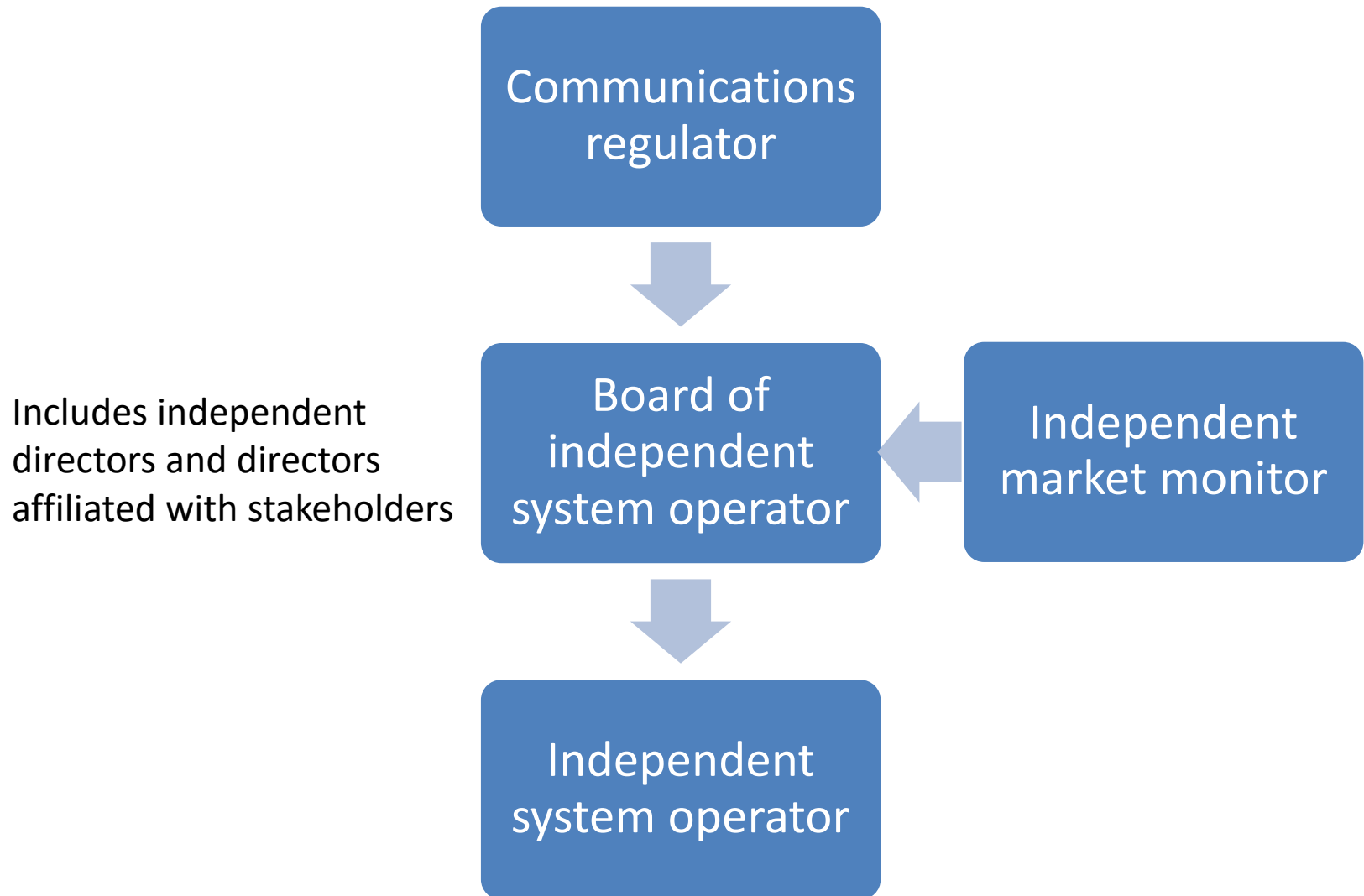
# Independent system operator

- Non-profit entity set up with simple mission  
*“To serve the public by operating a reliable and efficient market for open access mobile communications”*
- Analogous to system or grid operator in wholesale electricity markets

# Tasks of independent system operator

- Qualifies market participants and establishes any limits on each participant's bidding activities
- Reveals the yearly, monthly and hourly supply curves for the open access network
- Conducts the yearly auction
- Conducts the monthly auctions
- Conducts the real-time auctions
- Operates the open access market
- Settles all transactions on a monthly basis consistent with market rules and supply and demand realizations
- Provides information on market performance to market participants and the market monitor
- Improves the market as problems are identified

# Governance of market



# Spectrum auctions and competition policy

- Spectrum auctions still play an essential role in assigning and pricing new spectrum
- Competition policy will remain an issue, but can be addressed more simply and powerfully with open access
  - Set aside some spectrum for the open access network
  - Public receives value of spectrum, as determined over time in the open access network, rather than lump sum

# Conclusion

- Open access is the future of mobile communications
- Basis for time and location wholesale market (similar to restructured electricity markets)
- Market coexists with existing proprietary networks
- Assures scarce network resource is used efficiently
- Addresses competition issues of existing markets

# Sample Screen Shots

## Auction Schedule

Round	Duration	Start	End	Recess
Round 1	20 min	06:30 EDT	06:50 EDT	10 min
Round 2	20 min	07:00 EDT	07:20 EDT	10 min
Round 3	20 min	07:30 EDT	07:50 EDT	10 min
Round 4	20 min	08:00 EDT	08:20 EDT	10 min
Round 5	20 min	08:30 EDT	08:50 EDT	10 min
Round 6	20 min	09:00 EDT	09:20 EDT	10 min
Round 7	20 min	09:30 EDT	09:50 EDT	10 min
Round 8	20 min	10:00 EDT	10:20 EDT	

**Note:**

- All start and end times are in EDT.
- All future rounds are tentative and subject to change.
- indicates the round or recess is Active.
- indicates a past round.



Regions

**Products**

Product	Maximum Supply	Supply	Opening Price
PEA 1 (NY-Metro) (Peak)	60,675.000 GB/h	27,303.000 GB/h	\$0.50/GB
PEA 1 (NY-Metro) (Off Peak)	60,675.000 GB/h	27,303.000 GB/h	\$0.25/GB
PEA 2 (LA - Metro) (Peak)	44,251.000 GB/h	19,912.000 GB/h	\$0.40/GB
PEA 2 (LA - Metro) (Off Peak)	44,251.000 GB/h	19,912.000 GB/h	\$0.20/GB
PEA 3 (Chicago - Metro) (Peak)	21,603.000 GB/h	9,721.000 GB/h	\$0.40/GB
PEA 3 (Chicago - Metro) (Off Peak)	21,603.000 GB/h	9,721.000 GB/h	\$0.20/GB
PEA 4 (San Fran - Metro) (Peak)	21,208.000 GB/h	9,543.000 GB/h	\$0.40/GB
PEA 4 (San Fran - Metro) (Off Peak)	21,208.000 GB/h	9,543.000 GB/h	\$0.20/GB
PEA 5 (DC - Metro) (Peak)	19,654.000 GB/h	8,844.000 GB/h	\$0.40/GB
PEA 5 (DC - Metro) (Off Peak)	19,654.000 GB/h	8,844.000 GB/h	\$0.20/GB

**Regions**

Products

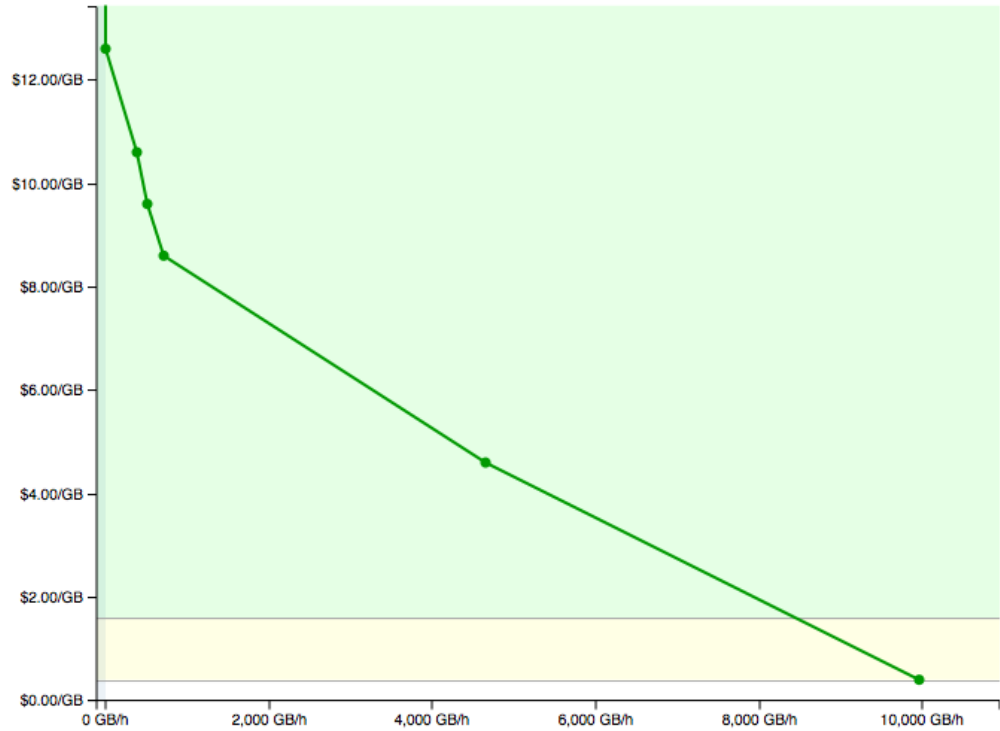
Region ID	Region Name	Published Maximum Supply	Percentage of Supply
<b>Subregions of PEA 1 (NY-Metro)</b>		<b>60,675.000 GB/h</b>	<b>100.00%</b>
09001	Fairfield	2,137.500 GB/h	3.52%
09003	Hartford	2,156.250 GB/h	3.55%
09005	Litchfield	431.250 GB/h	0.71%
09007	Middlesex	375.000 GB/h	0.62%
09009	New Haven	1,912.500 GB/h	3.15%
09011	New London	618.750 GB/h	1.02%
09013	Tolland	337.500 GB/h	0.56%
09015	Windham	262.500 GB/h	0.43%
34003	Bergen	2,043.750 GB/h	3.37%
34013	Essex	1,800.000 GB/h	2.97%

PEA 2 (LA - Metro) (Peak)   At \$  /GB hold  GB/h  

Your Forward Position: 0.000 GB/h

Maximum Supply in this Auction: 19,912.000 GB/h

	Price	Quantity	Commitment (2160 hours)
<i>Future Rounds</i>			
✉	<u>\$12.60/GB</u> ✎	0.000 GB/h	\$0
✉	\$10.60/GB 🗑	<u>380.000 GB/h</u> ✎	\$8,700,480
✉	\$9.60/GB 🗑	<u>512.000 GB/h</u> ✎	\$10,616,832
✉	\$8.60/GB 🗑	<u>712.000 GB/h</u> ✎	\$13,226,112
✉	\$4.60/GB 🗑	<u>4,655.000 GB/h</u> ✎	\$46,252,080
⬆	\$4.14/GB	5,230.429 GB/h	\$46,818,747
<i>Current Round</i>			
	\$1.60/GB	8,441.429 GB/h	\$29,173,579
<i>Price Floor</i>			
✉*	\$0.40/GB	<u>9,956.000 GB/h</u> ✎	\$8,601,984



## Bidding - Round 1

You can upload bids for all products in the form below:

No file selected.

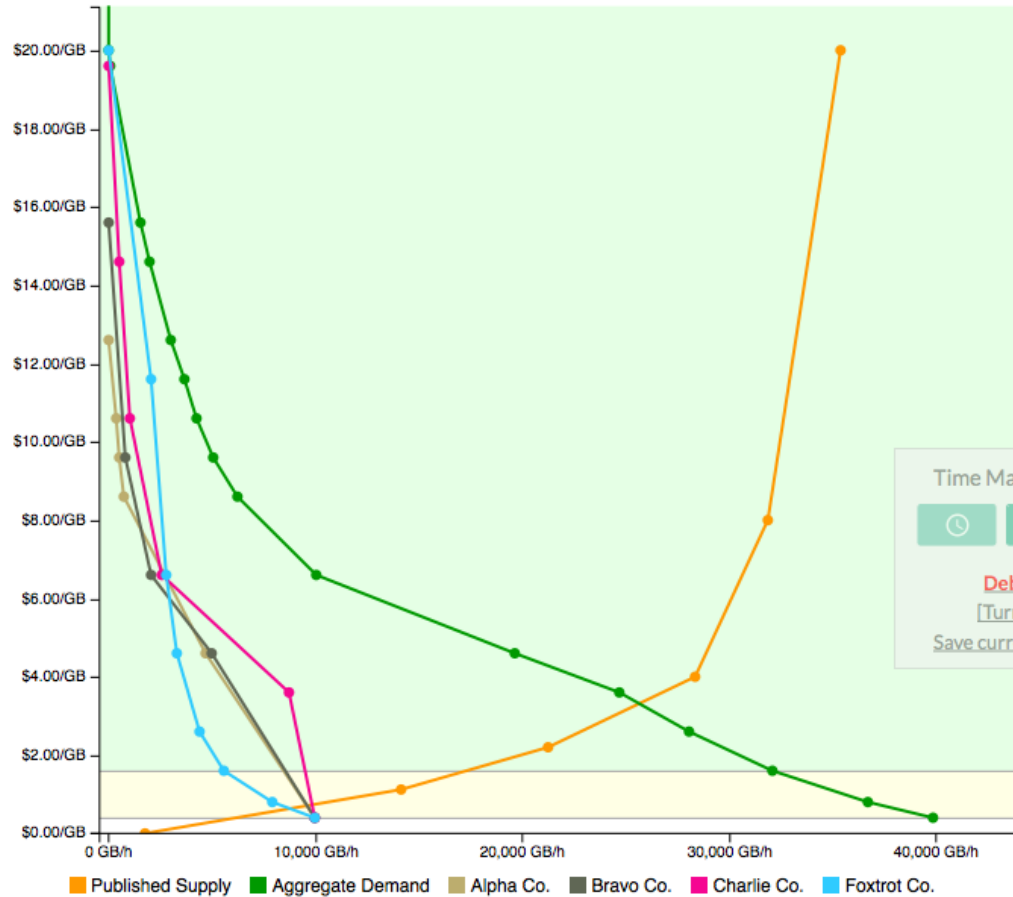
[Download a Sample File](#) or [Remove all Bids](#)

Product		Current Bidding Band	Forward Position	Maximum Commitment	# of Bids	
PEA 1 (NY-Metro)	Peak	\$0.50/GB - \$2.00/GB	0.000 GB/h	\$105,303,306	4	<a href="#">Edit Bids</a>
PEA 1 (NY-Metro)	Off Peak	\$0.25/GB - \$1.00/GB	0.000 GB/h	\$0	0	<a href="#">Edit Bids</a>
PEA 2 (LA - Metro)	Peak	\$0.40/GB - \$1.60/GB	0.000 GB/h	\$46,818,747	6	<a href="#">Edit Bids</a>
PEA 2 (LA - Metro)	Off Peak	\$0.20/GB - \$0.80/GB	0.000 GB/h	\$63,863,197	4	<a href="#">Edit Bids</a>
PEA 3 (Chicago - Metro)	Peak	\$0.40/GB - \$1.60/GB	0.000 GB/h	\$36,866,016	7	<a href="#">Edit Bids</a>
PEA 3 (Chicago - Metro)	Off Peak	\$0.20/GB - \$0.80/GB	0.000 GB/h	\$31,179,945	4	<a href="#">Edit Bids</a>
PEA 4 (San Fran - Metro)	Peak	\$0.40/GB - \$1.60/GB	0.000 GB/h	\$36,189,504	5	<a href="#">Edit Bids</a>
PEA 4 (San Fran - Metro)	Off Peak	\$0.20/GB - \$0.80/GB	0.000 GB/h	\$30,607,378	4	<a href="#">Edit Bids</a>
PEA 5 (DC - Metro)	Peak	\$0.40/GB - \$1.60/GB	0.000 GB/h	\$33,537,888	4	<a href="#">Edit Bids</a>
PEA 5 (DC - Metro)	Off Peak	\$0.20/GB - \$0.80/GB	0.000 GB/h	\$28,364,561	4	<a href="#">Edit Bids</a>

## PEA 2 (LA - Metro) (Peak)

Product has not yet cleared.	
Projected clearing price based on proxy bids	
Clearing Price	\$3.32/GB
Clearing Quantity	25,631.548 GB/h
Total Sold	\$183,808,957
Number of Buyers	4
Number of Sellers	0

Show Bidder Demand Curves



Time Machine: Running

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Debug level: 2  
[\[Turn off debug\]](#)  
[Save current auction state](#)

## Report Results for Round 1 to All Bidders

Region	Time	EOR Demand	EOR Supply	Excess Demand
PEA 1 (NY-Metro)	Peak	45,760.571 GB/h	23,730.667 GB/h	22,029.904 GB/h
PEA 1 (NY-Metro)	Off Peak	56,710.662 GB/h	23,730.667 GB/h	32,979.995 GB/h
PEA 2 (LA - Metro)	Peak	32,076.143 GB/h	17,306.667 GB/h	14,769.476 GB/h
PEA 2 (LA - Metro)	Off Peak	41,034.429 GB/h	17,306.667 GB/h	23,727.762 GB/h
PEA 3 (Chicago - Metro)	Peak	25,230.804 GB/h	8,448.978 GB/h	16,781.826 GB/h
PEA 3 (Chicago - Metro)	Off Peak	17,300.714 GB/h	8,448.978 GB/h	8,851.736 GB/h
PEA 4 (San Fran - Metro)	Peak	25,315.000 GB/h	8,294.489 GB/h	17,020.511 GB/h
PEA 4 (San Fran - Metro)	Off Peak	23,746.893 GB/h	8,294.489 GB/h	15,452.404 GB/h
PEA 5 (DC - Metro)	Peak	18,521.696 GB/h	7,686.800 GB/h	10,834.896 GB/h
PEA 5 (DC - Metro)	Off Peak	14,351.750 GB/h	7,686.800 GB/h	6,664.950 GB/h

Report Results to all bidders

Time Machine: Running

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**Debug level: 2**  
 [Turn off debug]

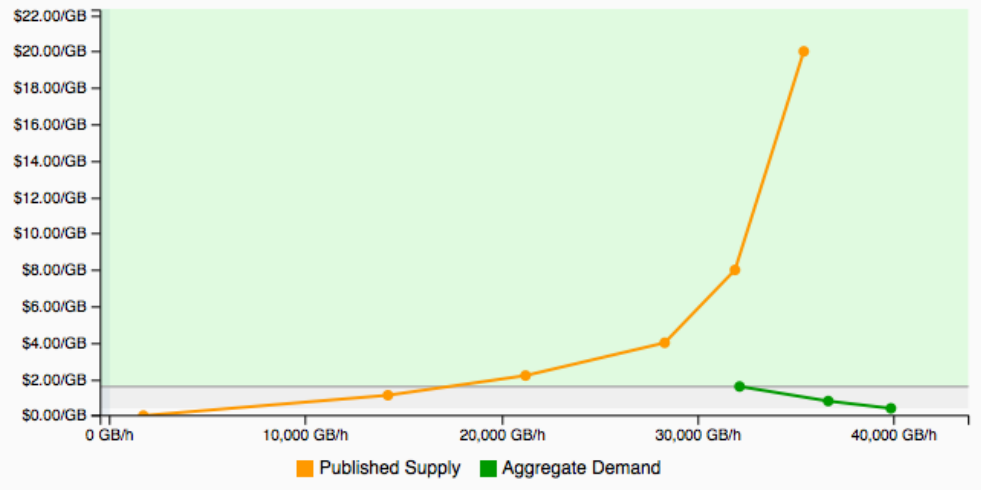
[Save current auction state](#)

Cleared Products    **Open Products**

### PEA 2 (LA - Metro) (Peak)

Product has not yet cleared.

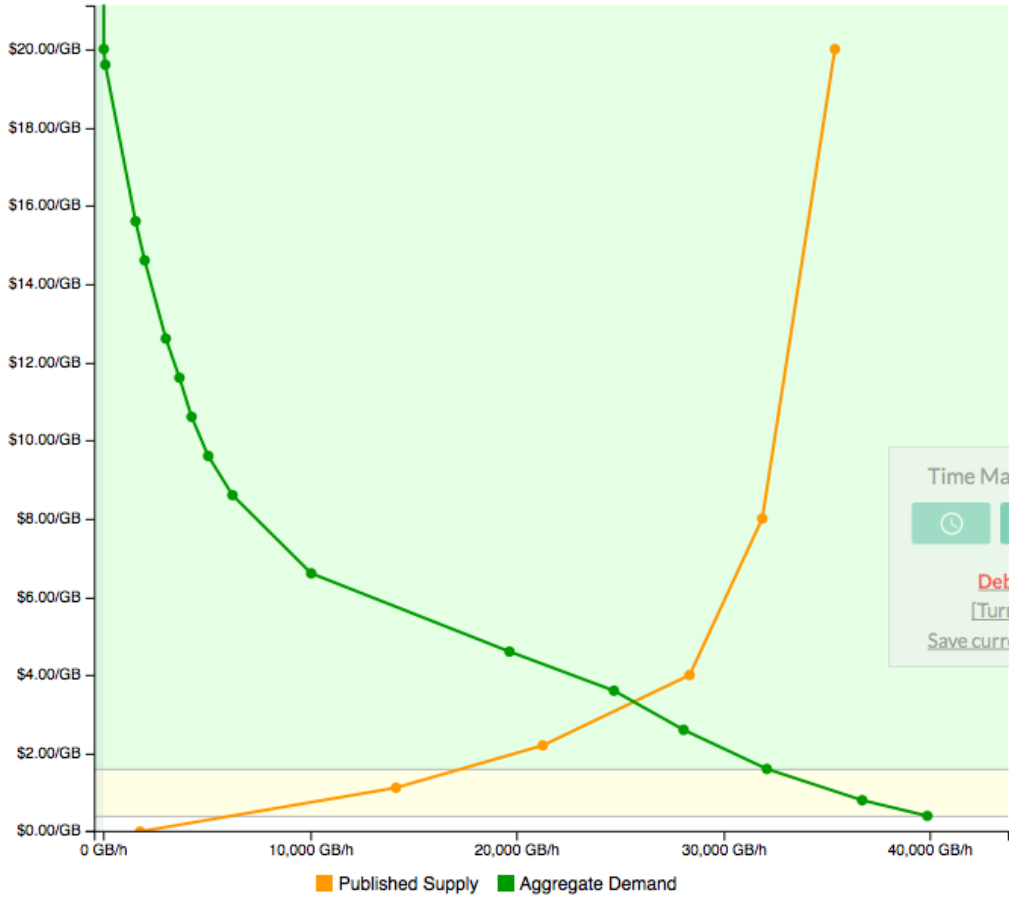
Supply at end of round	17,306.667 GB/h
Aggregate Demand	32,076.143 GB/h



### PEA 2 (LA - Metro) (Peak)

Product has not yet cleared.	
Projected clearing price based on proxy bids	
Clearing Price	\$3.32/GB
Clearing Quantity	25,631.548 GB/h
Total Sold	\$183,808,957
Number of Buyers	4
Number of Sellers	0

Show Bidder Demand Curves



Time Machine: Running

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Debug level: 2  
[Turn off debug](#)  
[Save current auction state](#)



## Bid Confirmation - Round 5

Round 5 ▾   [Expand All](#)

Region	Time	Bidding Band				Maximum Commitment (during the round)
		Min	Quantity	Max	Quantity	
<b>Total buying</b>			32,175.909 GB/h		29,668.544 GB/h	\$295,193,232
<b>Total selling</b>			0.000 GB/h		0.000 GB/h	\$0
PEA 1 (NY-Metro)	Peak	\$4.06/GB	10,531.067 GB/h	\$25.00/GB	10,171.634 GB/h	\$98,209,161
PEA 1 (NY-Metro)	Off Peak	\$0.25/GB	0.000 GB/h	\$12.50/GB	0.000 GB/h	\$0
PEA 2 (LA - Metro)	Peak	\$3.24/GB	6,371.514 GB/h	\$20.00/GB	5,967.628 GB/h	\$45,888,672
PEA 3 (Chicago - Metro)	Off Peak	\$1.62/GB	2,915.600 GB/h	\$10.00/GB	2,696.400 GB/h	\$31,101,356
PEA 4 (San Fran - Metro)	Peak	\$4.68/GB	3,250.360 GB/h	\$20.00/GB	2,639.517 GB/h	\$29,361,987
PEA 4 (San Fran - Metro)	Off Peak	\$2.03/GB	2,310.650 GB/h	\$10.00/GB	2,041.650 GB/h	\$29,502,659
PEA 5 (DC - Metro)	Peak	\$3.74/GB	4,144.393 GB/h	\$20.00/GB	3,698.790 GB/h	\$32,836,378
PEA 5 (DC - Metro)	Off Peak	\$1.62/GB	2,652.325 GB/h	\$10.00/GB	2,452.925 GB/h	\$28,293,018

## My Markets

Cleared Products

Open Products

Region	Time	Clearing		Auction Winnings for Alpha Co.		
		Price	Quantity	New Quantity Owned	Quantity Won	Total Cost
<b>Total buying</b>				<b>38,549.491 GB/h</b>		<b>\$376,952,879</b>
<b>Total selling</b>				<b>0.000 GB/h</b>		<b>\$0</b>
PEA 1 (NY-Metro)	Peak	\$4.11/GB	34,980.564 GB/h	10,487.234 GB/h		\$93,101,469
Fairfield				369.451 GB/h		
Hartford				372.692 GB/h		
Litchfield				74.538 GB/h		
Middlesex				64.816 GB/h		
New Haven				330.562 GB/h		
New London				106.946 GB/h		

## Markets

[Download the Auction Winning Results](#)

							Filter:		
Region	↑	Status	Clearing Price	Clearing Quantity	Total Sold	Excess Demand	Peak	Off Peak	
PEA 1 (NY-Metro)	<a href="#">Peak</a>	Cleared	\$4.11/GB	34,980.564 GB/h	\$310,543,455	-3,804.436 GB/h			
	<a href="#">Off Peak</a>	Cleared	\$2.40/GB	37,968.494 GB/h	\$590,486,019	-3,135.261 GB/h			
PEA 2 (LA - Metro)	<a href="#">Peak</a>	Cleared	\$3.32/GB	25,631.547 GB/h	\$183,808,950	-1,778.044 GB/h			
	<a href="#">Off Peak</a>	Cleared	\$1.86/GB	27,208.017 GB/h	\$327,932,787	-238.009 GB/h			
PEA 3 (Chicago - Metro)	<a href="#">Peak</a>	Cleared	\$4.68/GB	14,119.883 GB/h	\$142,735,073	5.219 GB/h			
	<a href="#">Off Peak</a>	Cleared	\$1.67/GB	12,569.047 GB/h	\$136,017,199	-1,052.468 GB/h			
PEA 4 (San Fran - Metro)	<a href="#">Peak</a>	Cleared	\$4.96/GB	13,981.757 GB/h	\$149,794,952	-1,001.973 GB/h			
	<a href="#">Off Peak</a>	Cleared	\$2.15/GB	13,703.693 GB/h	\$190,919,851	-626.518 GB/h			
PEA 5 (DC - Metro)	<a href="#">Peak</a>	Cleared	\$4.01/GB	12,580.875 GB/h	\$108,970,507	-331.863 GB/h			
	<a href="#">Off Peak</a>	Cleared	\$1.67/GB	11,418.263 GB/h	\$123,563,875	-947.805 GB/h			

Time Machine: Running

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Debug level: 2

[Turn off debug]

Save current auction state