



Power Market Solutions for a Highly Sector Coupled System - a US LMP Perspective

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**Presented at the ESIG 2023 Spring Technical Workshop
Tucson, AZ March 29, 2023**



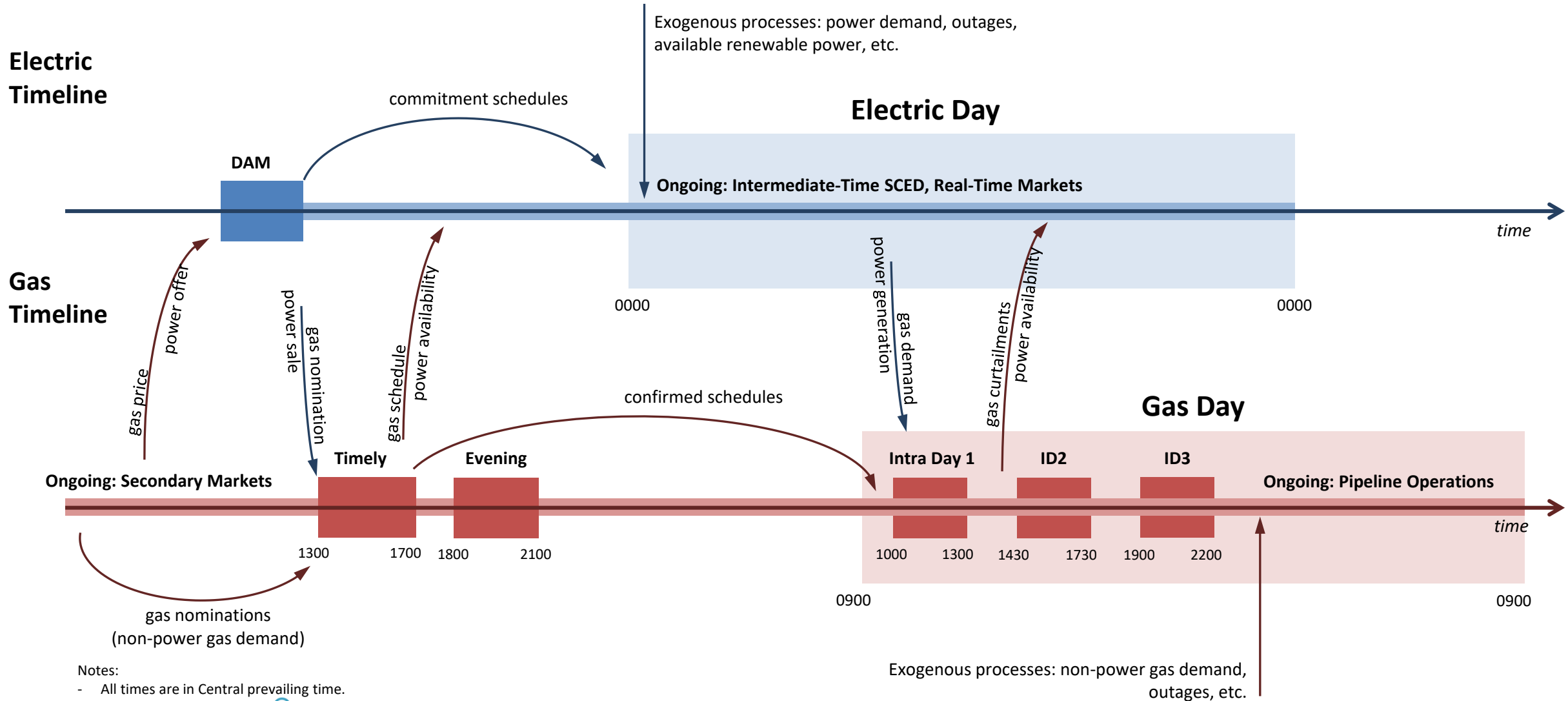
Why Nodal (LMP-based) Markets?

- The nodal or LMP-based market for electricity provides price formation mechanism that is most consistent with the physics and engineering of energy production and delivery
- The need for uplifting and ambiguous cost allocation mechanisms is minimized
- Nodal market design facilitates most optimal system operation without the need to satisfy administratively set side constraints followed by a subsequent (and sub-optimal) redispatch
- Nodal market design offers the most precise investment and technology development signals of various kinds
... albeit not always followed

US Gas – Electric Coordination as an Example of a Sector Coupled System

- Summary overview of Gas- Electric Coordination in the US
- Summary of Gas – Electric Challenges in the US
- The Gas – Electric Co-Optimization Ideas and the GECO project
- Lessons Learned

Current Parallel Operations of Natural Gas and Electric Markets



Notes:

- All times are in Central prevailing time.
- The gas cycles depicted are the standard cycles required by FERC. Each pipeline may offer additional cycles. Under emergency conditions scheduling could be done outside of these cycles.

Summary of Gas-Electric Challenges

- Operational Challenges:
 - Flexible gas-fired generation capacity lacks fuel supply flexibility
 - Flexibility is crucial in power systems, as supply must match demand *continuously and instantaneously* (there is no equivalent to line pack)
 - The variability and unpredictability of gas-fired generation pose challenges to pipeline operations
 - Gas supply constraints may constitute a common mode reliability event for the **operational reliability** of the electrical system
- Planning/Long-Term Challenges:
 - Gas-fired power plants tend to not procure firm gas transportation
 - Under extreme conditions, there have been severe gas pipeline constraints that limited supply to gas-fired generation
 - Gas supply constraints may constitute a common mode reliability event for the **adequacy** of the electrical system
- Anticipated continued growth of the gas-fired generating fleet will exacerbate these challenges

Operational challenges should be addressed first

Today's Key Gas-Electric Coordination Deficiency

Gas-fired power generators...

- Tend to be flexible units capable of generating upon relatively short notice,
- Are active in the 5-minute real-time power markets, and can change their outputs frequently, following changes in system needs,
- Provide the bulk of operating reserves in some regions – requires the ability to change output immediately, as directed by the power system operator,
- It is difficult to forecast burn rates for these units on a day-ahead basis.

There are no liquid and transparent intra-day gas markets in which gas-fired generators can procure gas as needed, and under relatively short notice.

- Most flexible gas-fired power plants purchase gas bilaterally from marketers who manage a portfolio of gas resources.
- An alternative is to purchase gas from a supplier and transportation rights from a shipper – a time consuming, multi-party process in an illiquid market.

Long Recognized Gas Industry Challenge

From October 10, 2018 S&P Global Article

Fast responses to power generation demand shifts means pipelines will need to be able to enhance gas deliverability and increase market storage within their service areas, Will Brown, an executive with Kinder Morgan Inc., told the LDC Gas Forums Rockies and West conference.

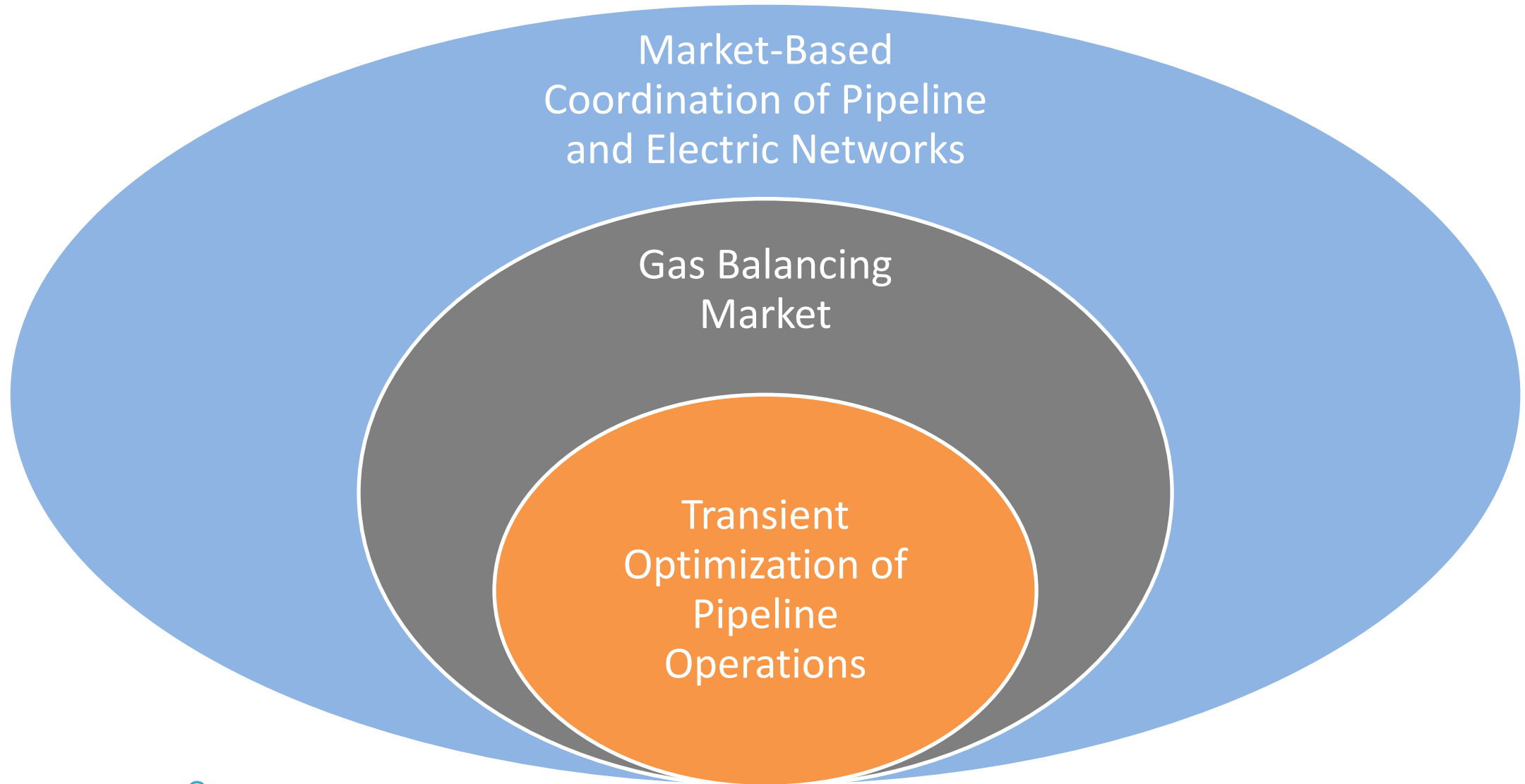
Pipelines have to be able to deliver large volumes of gas on short notice, a major shift from traditional model of supplying gas to industrial and local distribution markets. "Natural gas deliverability is the ability to deliver gas at the required location, time, pressure and quantity," Brown said. "The higher deliverability requires more capacity reservation, more known notice, more hourly service, and more reliance on linepack and market area storage."

A growing concern is whether pipelines can support generators providing ancillary services and compensating for sudden ramps in renewable generation .

GECO Project Summary

- Project objective is to develop methods, model, algorithms and an associated market design for a dramatically improved coordination and / or co-optimization of wholesale natural gas and electric physical systems and economic markets on a day-ahead and intra-day basis
- Formal Project Title: *Coordinated Operation of Electric And Natural Gas Supply Networks: Optimization Processes And Market Design*
- Leading Organization: Newton Energy Group LLC
- ARPA-E Program: OPEN-2015
- Project started: 2016
- Project completed: 2019
- ARPA-E project summary: <https://arpa-e.energy.gov/?q=slick-sheet-project/gas-electric-co-optimization>

The GECO Approach



Transient Optimization

Economic Optimization of Pipeline Operation: a Conceptual Formulation

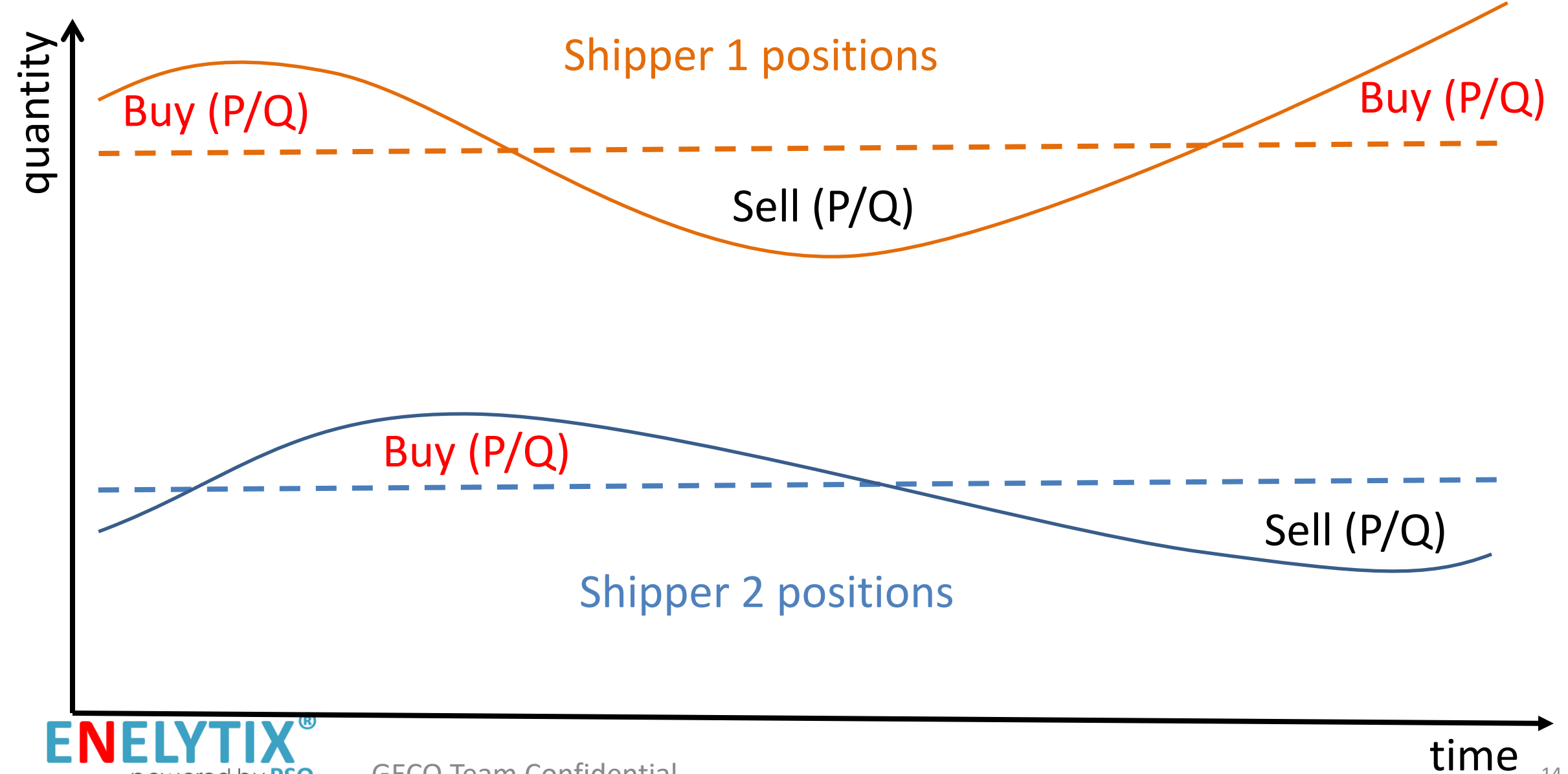
- A two-sided auction
- Conducted on gas pipeline network subject to engineering constraints
- Participants: buyers and sellers of gas submitting Price/Quantity (P/Q) offers/bids
- Offers and bids are node-specific, with hourly time step for an optimization horizon (e.g., 36 hours)
- Auctioneer's objective function: maximize market surplus between accepted bids and offers less compressor costs of running the pipeline, summed over the optimization horizon

Locational Trade Values of Natural Gas

- Auction clearing will produce Locational Trade Values (LTVs) of natural gas as shadow prices of nodal flow balance
- LTVs are highly granular:
 - any node
 - hourly or sub-hourly time step
- LTVs are fully consistent with the physics of gas flow and the pipeline engineering constraints
- Transacting parties could have a guarantee of gas delivery at settled prices

Gas Balancing Market

Gas Balancing Market will trade deviations from ratable schedules



High Level Overview of the Gas Balancing Market

The Gas Balancing Market (GBM) would:

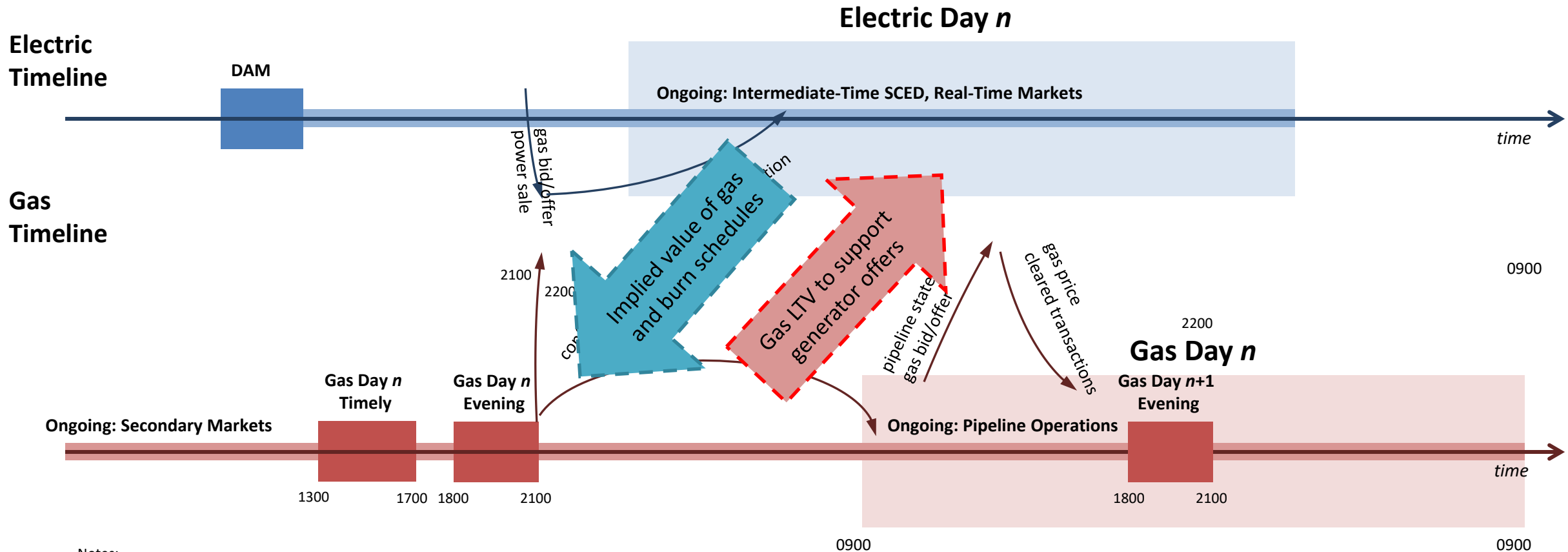
- Be pipeline specific
- Have **voluntary** participation
- Honor existing transportation rights and contracts
- Enable trades of hourly imbalances from ratable schedules
- Assure that intra-day transactions cleared in the market are physically implementable
- Enable intra-day gas transactions between parties in a liquid, transparent, flexible and simple manner
- Provide transparent pricing signals to all gas players to inform decision making
- Enable more economically efficient utilization of the gas and power infrastructures

GBM Outcome

- Hourly schedules for receipt and delivery:
 - schedules result from
 - Cleared market buy/sell positions and/or
 - Self-schedules
- Hourly Gas Locational Trade Values (LTV) of gas by node (receipt and delivery points)
- Cleared schedules are settled at LTVs

Gas Electric Co-Ordination with GBM

Value based Intra-day coordination of gas and electric systems



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Granular Pricing Signals at Work

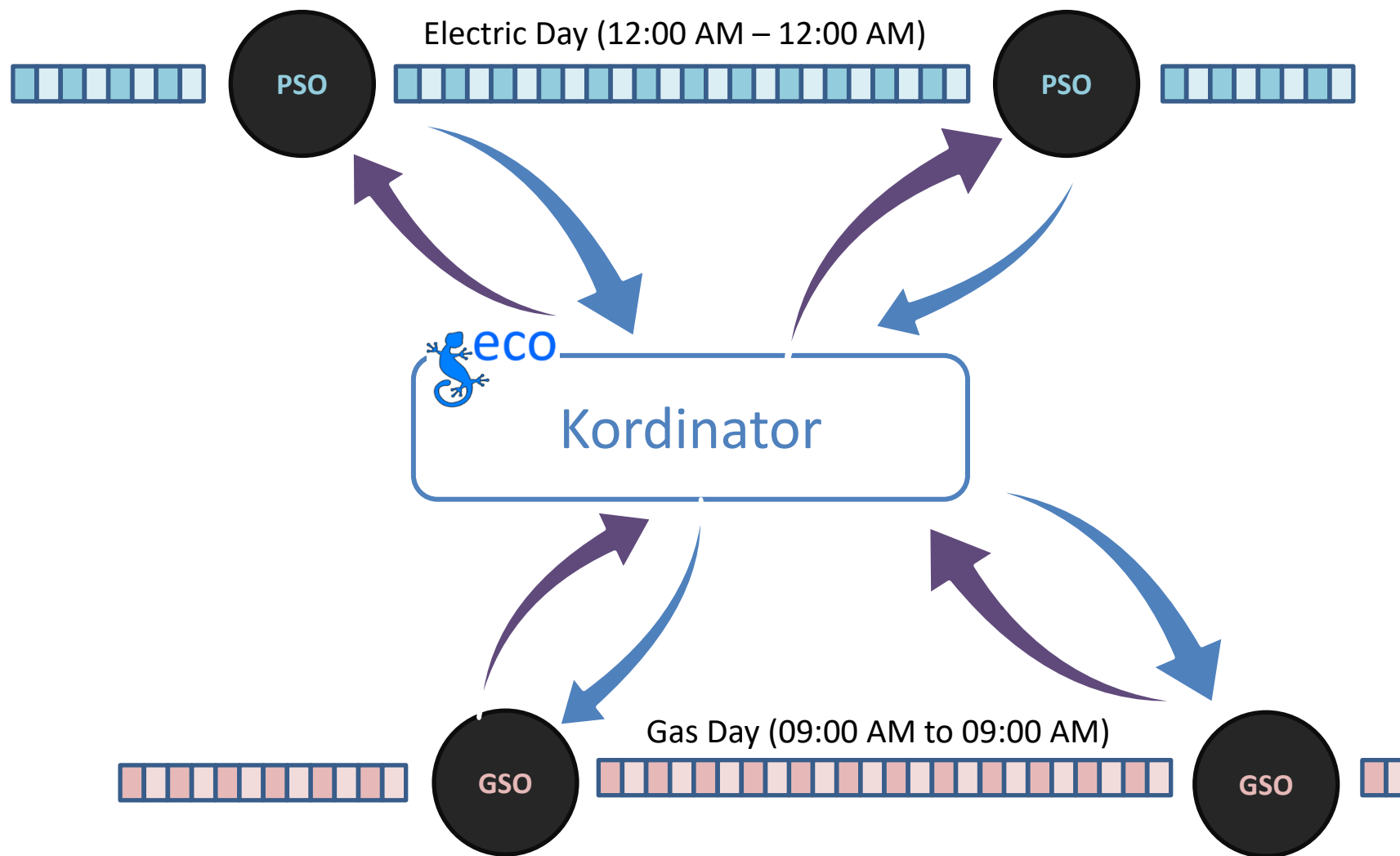
- Gas Pipeline Side

- Relief of pipeline constraints through
 - LTV-sensitive optimization of compressors
 - Redispatch of electric generation
- Help pipeline customers make investment decisions
- Help pipeline owners to
 - Identify constrained system elements with better granularity
 - More precisely assess economic benefits of alternative solutions
 - Justify investments into economic solutions before regulatory agencies

- Electric Network Side

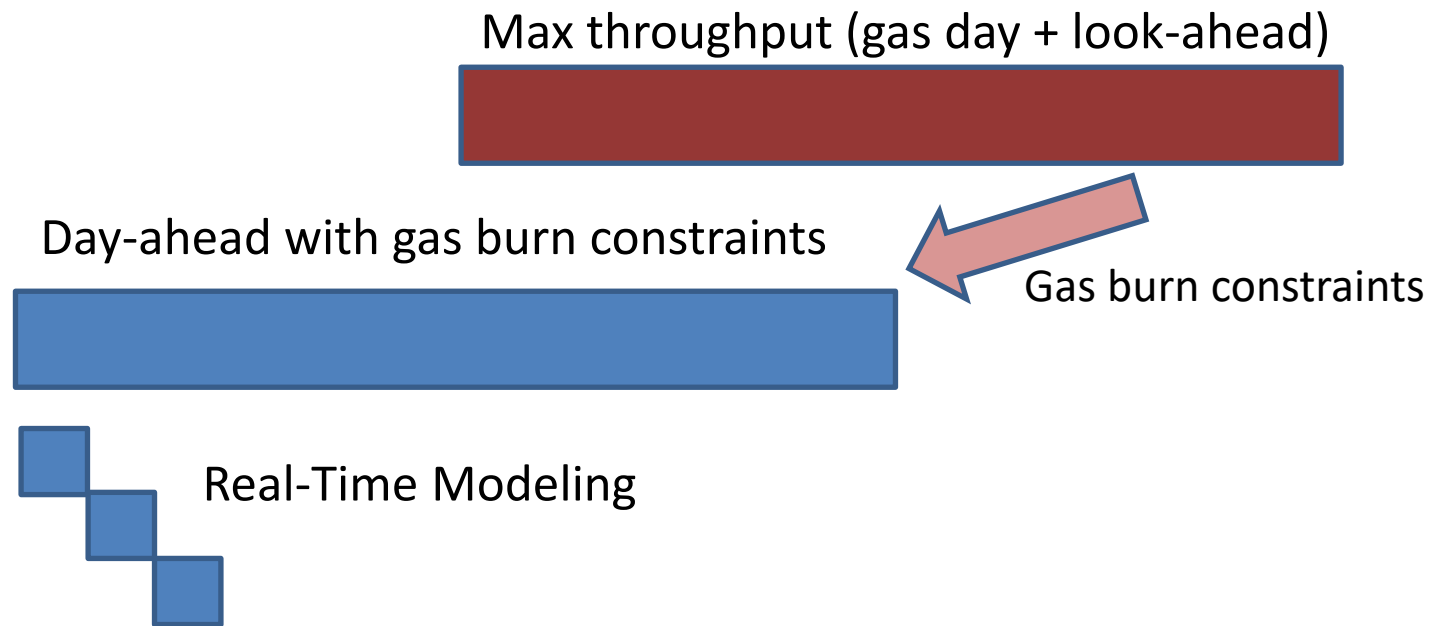
- Hourly gas trade values (LTVs) to support bidding into DA and RT markets
- Simplifies gas purchases for gas-fired fast-start power plants that clear in the real-time power markets and/or that are called upon to provide ancillary services
- Redispatch of electric generation in response to high gas LTV under scarcity caused by pipeline constraints
- Transparent economic signal to help generating companies to determine the level of FT coverage they need to manage risk

Modeling Gas-Electric System in GECO ENELYTIX



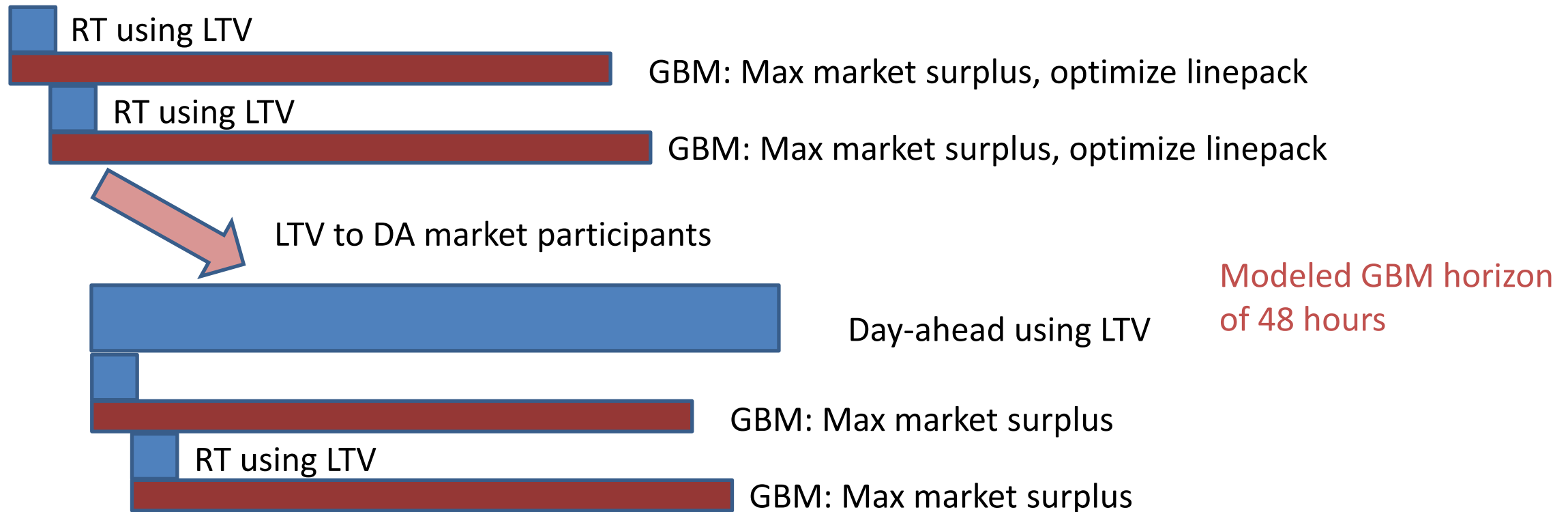
Modeling Business as Usual (BAU) in GECO ENELYTIX

- Business as Usual Description
 - Indicative day-ahead gas procurement by generators
 - Generators schedule output and gas burn day-ahead
 - Generators schedule/confirm gas deliveries with pipeline
 - Generators burn gas and produce power in real-time



Modeling GBM in GECO ENELYTIX

- Interactions of DA and RT with GBM
 - GBM interacts with RT but it has long look-ahead
 - GBM look-ahead provides hourly price discovery for DA



Summary of Results

- Gas price impact for GBM participants
 - Depending on the location GBM participants would see 3% to 12% in gas price reduction from the actual day-ahead zonal index paid
 - Participating generators see increase in operating margin by 45% - 380% depending on the location
 - **Most of the instantaneous congestion in that pipeline segment could have been eliminated**
- On the electric side, we observed reduction of production costs and electricity prices
 - System-wide RT production costs reduced by 2.2% to 2.8%
 - Reduction in LMPs within the zone where most of the affected capacity is located by 2.1% - 2.3%

Lessons Learned

- Development of better coordinated markets based on improved optimization and market-based interactions is technically feasible
- If implemented, it would improve system efficiency, reliability and a range of other indicators
- Institutional barriers are significant
 - Regulated entities may not always see benefits in creating competitive markets
 - Non-regulated entities operating in imperfect markets are not always interested in improving market efficiency
- Reforms need champions