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Natural Gas Network Modeling Workshop

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Purpose

- Compare and contrast various model constructs and approaches for representing natural gas market behavior
- Interactive discussion on which approaches are best for NGTDM redesign
- Extension of approaches to development of a new International Natural Gas Model (e.g., noncompetitive aspects, data issues)

Agenda

- Overview of NGTDM
- Requirements of redesign
- Overview of other models
  - Gas Market Model (GMM)
  - INGM
  - GPCM
  - MarketBuilder Models/RWGTM
  - World Gas Model
- Key Topics Discussion
  - Regional detail
  - Temporal aggregation
  - Capacity expansion & tariffs
  - Foresight
  - Formulation type
  - Int’l issues

Overview of Current NGTDM

- Highly aggregated network (12 domestic regions, 2 seasons, and peak month) with predetermined flow direction
- Seasonal storage represented with two seasons
- Uses heuristic algorithm that applies average pricing to derive representative regional prices, benchmarked to historical values
- Flows start from historical levels and progressively move to lower cost options, based on a sharing algorithm.
- Does not readily adjust to large changes (e.g., AK pipeline).
- Flows move based on variable pipeline rates
- Pipeline capacity expansion occurs when flows exceed existing capacity, given a tariff curve with a large increase at capacity

Requirements for new NGTDM

- Given annual/regional consumption levels and supply response to price, determine production levels and supply and delivered prices.
- Establish import/export levels to Canada, Mexico, and as LNG
- Endogenously set pipeline and storage capacity

- Regional/seasonal detail
- Supply/demand representation
- Pipeline tariffs
- Flows and capacity expansion (foresight)
- Imports/exports, including Canada and Mexico
- Delivered prices
- Benchmarking

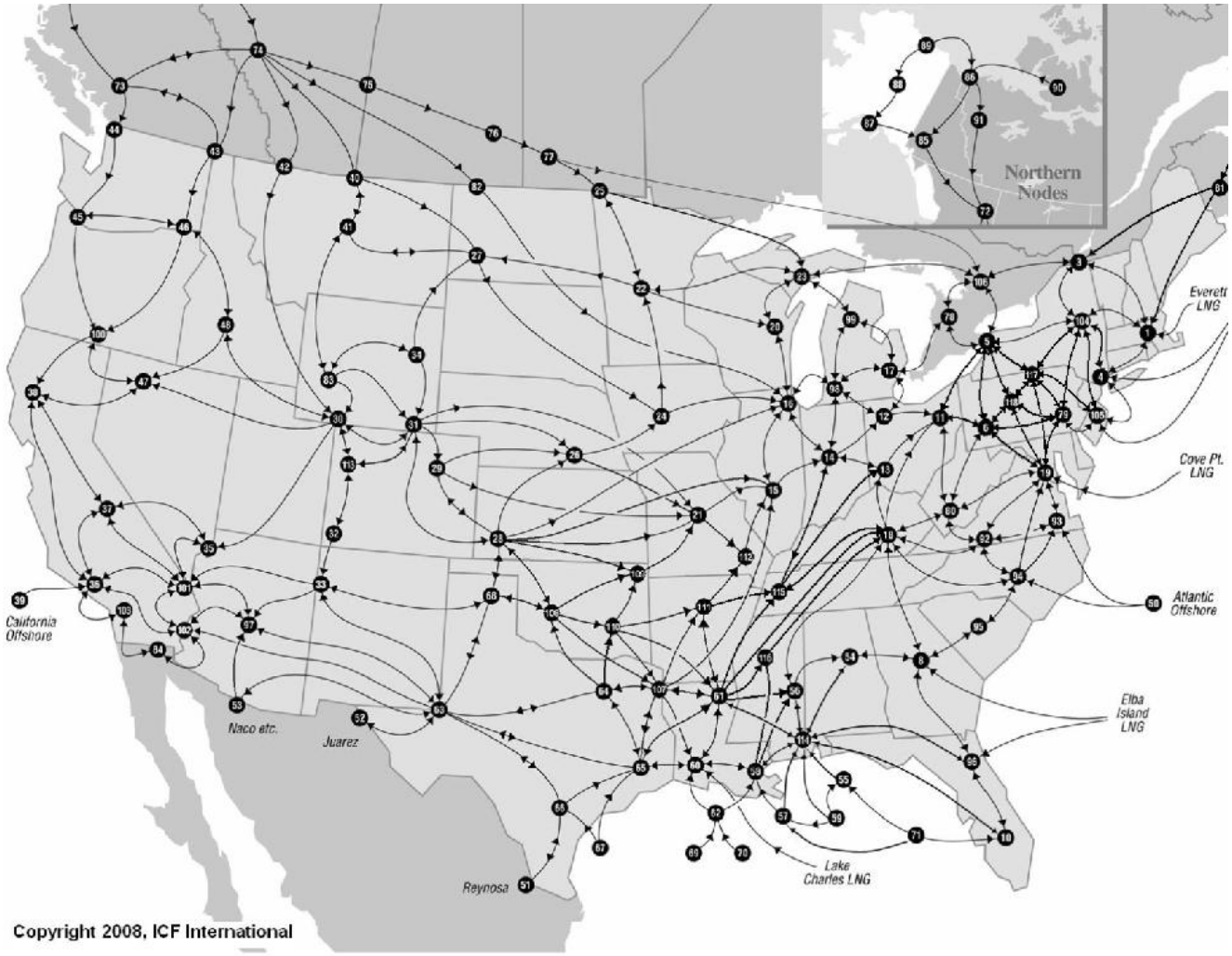
Other model overviews

Model Name	Owner
Gas Market Model (GMM)	ICF
INGM	EIA
GPCM	RBAC
Tanner Prototype	EIA
MarketBuilder - North American Gas Model	Deloitte
MarketBuilder - World Gas Model	Deloitte
MarketBuilder - RWGTM/BIWGTM	Rice Univ
World Gas Model	Gabriel-UMd

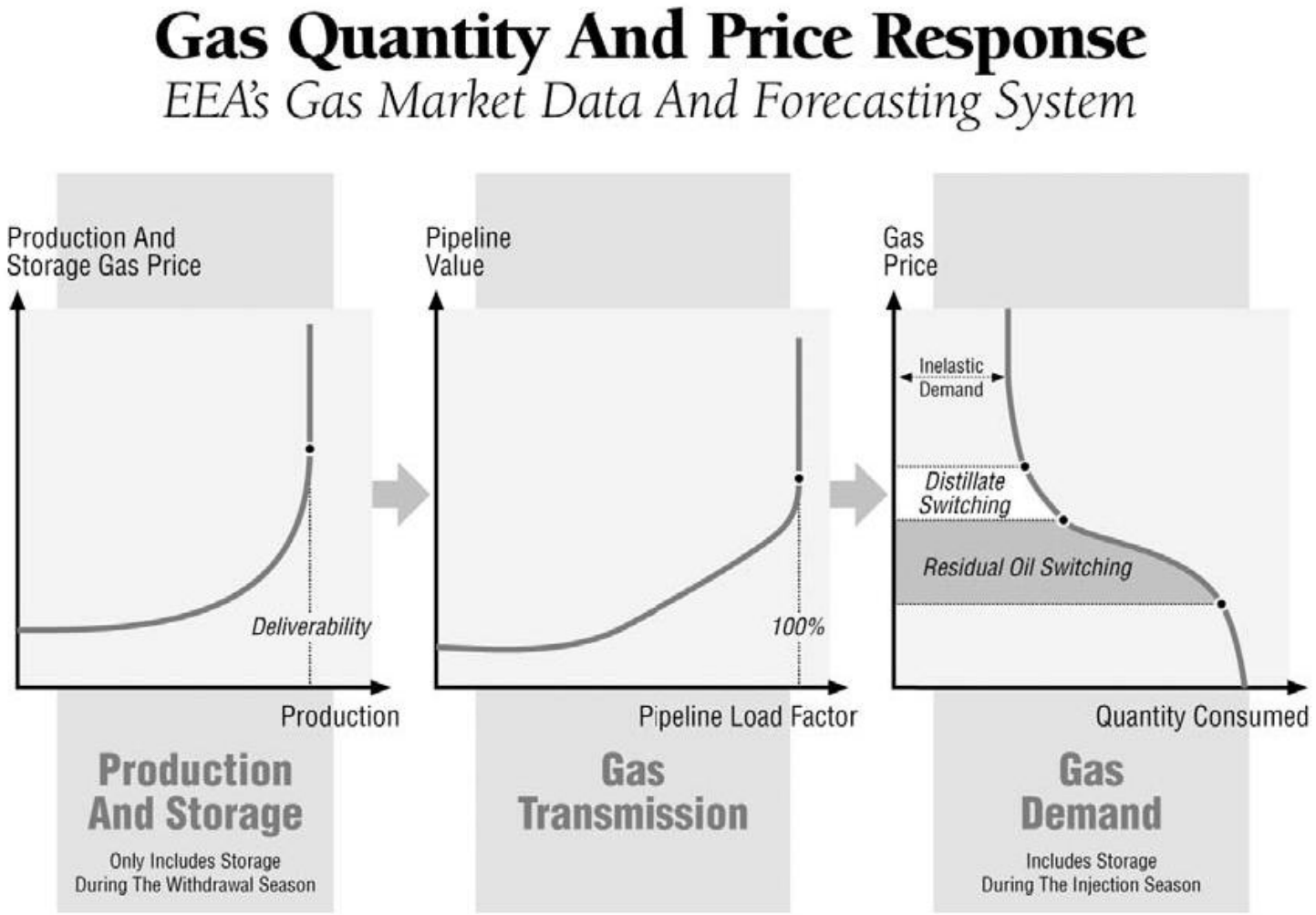
Gas Market Model

- Quadratic programming
- Competitive market
- Monthly time periods, no foresight
- North American model with 121 regions and roughly 400 pipelines aggregated to corridors throughout the U.S. and Canada
- Exogenous pipeline and storage capacity expansion based on analyst judgment
- Calibration done by changing model assumptions

GMM Network


Northern Nodes
Everett LNG
Cove Pt. LNG
Atlantic Offshore
California Offshore
Elba Island LNG
Naco etc.
Juarez
Reynosa
Lake Charles LNG
Copyright 2008, ICF International

GMM Cost/Price Curves



Source: ICF, *2010 Natural Gas Market Review*, August 2010.

International Natural Gas Model

- Linear Program – maximize producer and consumer surplus
- Non-competitive behavior represented with constraints
- 61 regions
- 3 seasons
- Supply curves consider government take
- Demand curves from WEPS+ and NEMS for U.S.
- Supply & demand curves linearized
- Unit transportation costs
- LNG will flow based on marginal prices

INGM Capacity Expansion

- Near-term – fixed at projects under construction and those highly likely to be completed
- Mid-term – no minimum capacity, maximum capacity includes projects reasonably likely to be completed
- Long-term – no bounds set. Expansion determined by including asset operator profit in the objective function, thus, maximizing revenue from the asset minus investment and operating costs along with consumer and producer surplus.

INGM Foresight

Two Options:

- Perfect Foresight – solve for entire time horizon at once

- Rolling Optimization - solves annually in the early years of the forecast and then solves for groups of years at a time.

GPCM

- Linear program - competitive markets, market-clearing solution
- Monthly time periods
- North American Model
- 210 pipelines modeled individually, not aggregated
- Over 5000 nodes
- Solves over entire time horizon at once (perfect foresight)

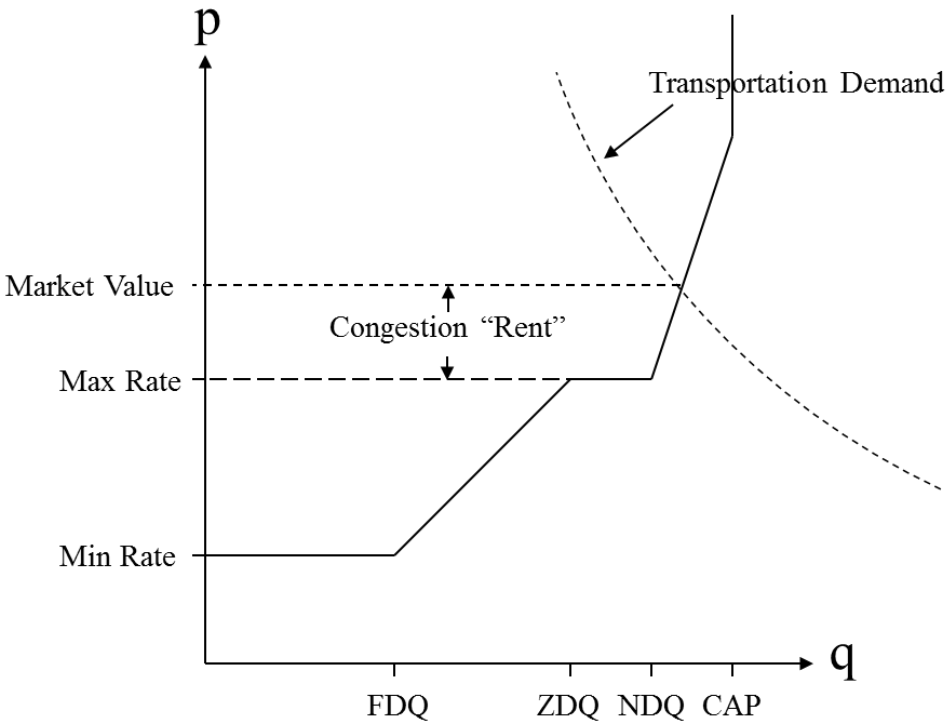
GPCM Network

Source: RBAC, *GPCM Natural Gas Forecasting System Presentation*, May 2014.

GPCM Cost/Price Curves

- Supply, demand, transportation curves are linearized
- Current version of the model sets the supply curves at the beginning of the forecast so past production does not impact future supply
- Storage costs are not based on capacity utilization

GPCM Transportation Curve



FDQ = Full Discount Quantity
ZDQ = Zero Discount Quantity
NDQ = Negative Discount Quantity (congestion)

Max Rate = Interruptible Commodity Charge
Min Rate = Firm Commodity Charge
Max Flow = System Capacity of Zone = Deliverability

Source: RBAC, *GPCM Natural Gas Forecasting System Presentation*, May 2014.

GPCM Capacity Expansion

- Optional endogenous feature
- Parametric function
- User inputs
  - year to activate feature
  - hurdle cost of expansion
  - maximum % of expansion allowed

GPCM Calibration

- Algorithm used to find values of parameters (such as FDQ, ZDQ) so that model results best match history

- Benchmarking from 2006-present

MarketBuilder Models

- Agent based microeconomic modeling framework
- Each agent (producer, transporter, consumer, etc.) maximizes its own profit
- Allows for imperfect market behavior
- Framework used to create unique models by allowing users to input their own data and equations that describe agent behavior
- Users can define agents at the level of aggregation desired
- Nonlinear supply (Hotelling), demand, transportation curves
- Non-stochastic

MarketBuilder Models – cont.

- Producers maximize the net present value of resource extraction, considering current and future prices. Producers will accelerate or delay resource extraction based on anticipated prices.

- Producer and consumer agents are linked through the transportation network. These links transmit prices and flows. A link from a supplier to a market with high prices will raise prices back to the supply node.

- Capacity expansion is endogenous to the model with investment occurring to maximize the net present value of the expansion given the impact on current and future prices.

MarketBuilder Model Solution

- No arbitrage
- Not required to be economically efficient
- No maximization of social welfare
- Equilibrium found using Walrasian auction process
  - At each node in the network, a set of input and output prices for all times of interest are guessed. If demands are higher than supplies at these prices, the prices are raised. If the reverse is true, prices are lowered. This continues until supplies and demands equilibrate across the network for all times.
- Solution algorithm takes advantage of parallel processing

MarketBuilder - North American Gas Model

- Database of all gas plays, 300 demand nodes, pipelines
- User defines agents/aggregation

MarketBuilder – World Gas Model

- 821 regions and sub-regions
- 708 demand nodes
- 1910 pipeline arcs
- Total of 5500 nodes
- Emissions credits market

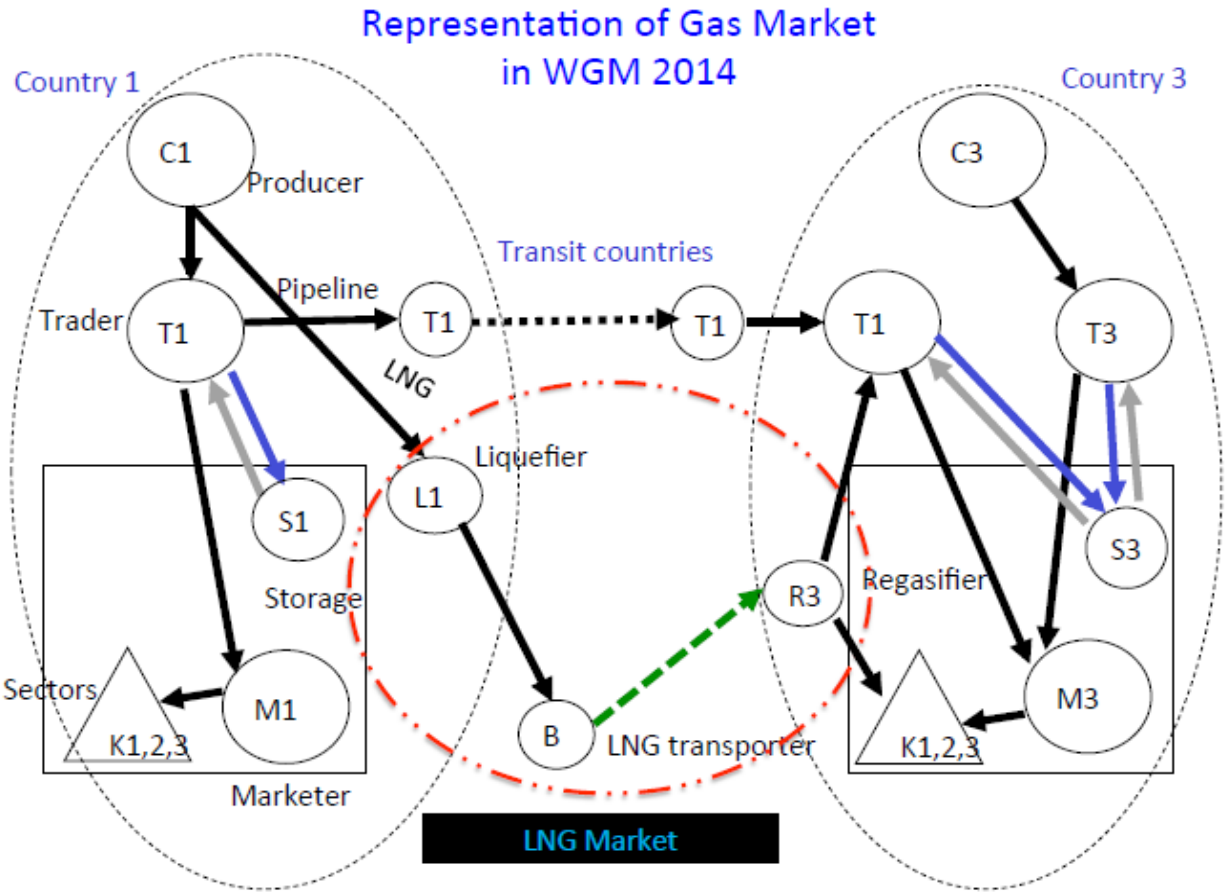
World Gas Model

- Mixed Complementarity Program
- Market power/game theory
- Convex non-linear functions
- Each player (producer, marketer, etc) has its own optimization problem
- KKT conditions for each optimization problem are combined with market clearing conditions and inverse demand curves to create the MCP
- Pipeline and storage capacity are determined endogenously

WGM Network

- 41-80 production/consumption nodes
- 2 seasons
- Demand sectors represented by inverse demand functions
- Traders act as the marketing arm of producers via the pipeline grid and may exercise market power by withholding supplies.
- LNG contracts set minimum constraints but are gradually phased out to represent further development of the LNG spot market in the future.
- Regasifiers are considered to be Nash-Cournot players with respect to storage operators and end users.
- Pipeline operators charge traders a regulated price to move gas. A congestion fee in the model ensures that pipeline capacity is allocated optimally.

WGM Nodal Representation



Source: Gabriel, Steven A., Seksun Moryadee, *The Competition in the European Gas Market: Using the World Gas Model (2012 and 2014 Versions*

Regional Aggregation
How Much is Enough?

Model Name	Regions
NGTDM	12
Gas Market Model (GMM)	110
GPCM	Not regional, 5000 nodes
MarketBuilder - North American Gas Model	User defined, but data provided on all gas plays, 300 demand nodes
RWGTM	900 nodes

Regional Aggregation
Factors to Consider

- Level necessary to perform EIA analyses
  - Industry models may be more detailed because of client needs
  - short-term versus longer-term issues
- Data availability and maintenance
  - Some data for industry models comes from sources that are not publicly available
- Run time, analyst time, convergence
- Behavior of pricing algorithm in aggregate versus more detailed network
- Masking network issues – bottlenecks, bidirectional flows

Temporal Aggregation

Model Name	Seasons
NGTDM	2
Gas Market Model (GMM)	monthly
INGM	3
GPCM	monthly
Tanner Prototype	4
MarketBuilder - RWGTM/BIWGTM	
World Gas Model	2

Temporal Aggregation
Factors to Consider

- Level necessary to perform EIA analyses
  - Industry models may be more detailed because of client needs
  - short-term versus longer-term focus
- Impact on modeling storage
- Impact on capacity expansion decisions
- Data availability and maintenance
  - Some data for industry models comes from sources that are not publicly available
- Run time, analyst time, convergence

Capacity Expansion & Tariffs

- Tariffs
  - Variable versus fixed rates
  - Variable rates more than fuel usage charges?
  - How are rates set and degree of importance?
  - Need to tie to published rates and relation to basis differentials

- Capacity Expansion
  - Determined endogenously in most of the models.
  - Determine concurrently with pipeline flows?
  - Include the cost of expansion in the pipeline tariff curve reflecting a hurdle rate required for expansion to be considered profitable.
  - Importance of look-ahead

Foresight

- Perfect foresight
- Rolling optimization
- Implication for capacity expansion
- Implication for production
- Convergence issues in NEMS

Formulations

Model Name	Type
Gas Market Model (GMM)	NLP
INGM	LP
GPCM	LP
Tanner Prototype	NLP
MarketBuilder - North American Gas Model	Agent-based
MarketBuilder - World Gas Model	Agent-based
MarketBuilder - RWGTM/BIWGTM	Agent-based
World Gas Model	MCP

Formulation
Factors to Consider

- Market competition/max social welfare
- Impact of linearizing functions
- Ease of formulating
- Flexibility
- Solution algorithms
- Run time
- Convergence/Alternate optima

Formulation - LP

- Linear Programming
  - Linear objective function and linear constraints
    - Linearize non-linear functions using piecewise linear curves
  - Competitive market
    - Represent non-competitive aspects using constraints
    - Option to limit flow decision to noncontracted volumes
  - Maximize social welfare
  - “knife-edge” effect

Formulation - NLP

- Nonlinear Programming
  - Nonlinear objective functions and/or constraints
  - Competitive market
    - Represent non-competitive aspects using constraints
    - Option to limit flow decision to noncontracted volumes
  - Maximize social welfare
  - What is impact on convergence compared to LP?
  - Does run time increase compared LP?

Formulation - MCP

- Mixed Complementarity Problem
  - MCP is a set of inequalities, equations, and complementarity for the inequalities with their nonnegatively-constrained variables (free variables associated with equations).
  - Each player in market modeled with own optimization problem
  - Noncompetitive aspects of market Market power/game theory
  - Nonlinear functions
  - Ability to explicitly include prices in the formulation, as well as have a significant amount of feedback between the sectors/players
  - KKT conditions for each optimization problem are combined with market clearing conditions and inverse demand curves to create the MCP
  - Solve set of equations and unknowns

Formulation – Agent Based

- Agent Based
  - Each player in market modeled with own optimization problem
  - Imperfect market behavior
  - Nonlinear functions
  - How does formulation differ from MCP?
    - Ease of formulating
    - Difference in results
  - Commercially available solver?

International Model Considerations

- Regional aggregation
- Interface with NEMS
- Competitive markets
- Market Power
- Nonlinear functions
- Limited data