



MISO Gas-Electric Planning Workshop

August 18, 2017
Eagan, MN

Agenda

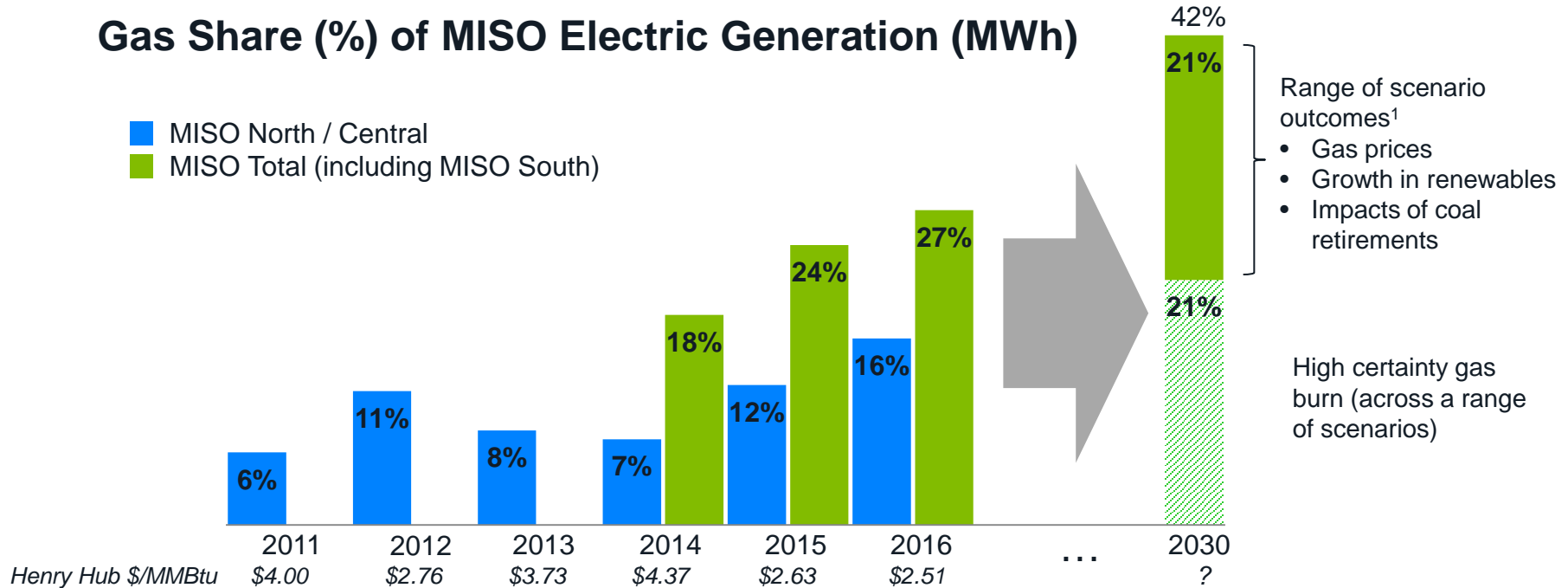
- Review of past Gas-Electric coordination efforts
- Highlights on non-planning Gas-Electric items
 - Operations/Coordination
 - Strategy/External Studies
- Introduction to natural gas modeling tools
- Description of gas modeling enhancements in MTEP18
- Interactive walkthrough of gas price forecasting with GPCM



Review of MISO's Past Gas-Electric Initiatives

Gas demand has grown and MISO's evolving fleet will propel gas demand even higher

Gas Share (%) of MISO Electric Generation (MWh)



Installed gas capacity is projected to increase 8,000 MW in the queue through 2020²

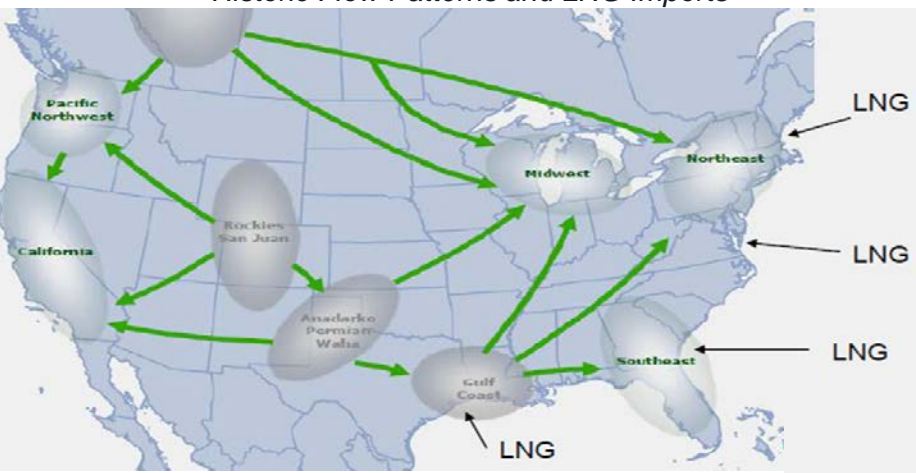
¹ - MISO MTEP17 sensitivities with range of gas prices (mid-case +/- 30%)

² - MISO Interconnection Queue as of March, 2017

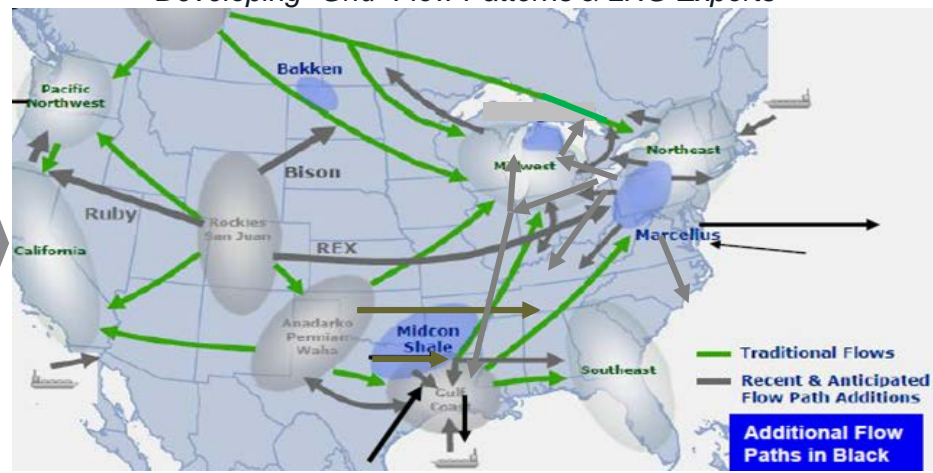
Significant changes on the gas system are driving impacts across the MISO region

- Increased flows to MISO from Marcellus/Utica on new-build pipelines and pipeline reversals are improving MISO supply diversity
- U.S. gas production from non-traditional supply regions continues to be favorable, causing flatter prices
- Perceived sustained long-term abundance is driving Liquefied Natural Gas (LNG) exports from facilities like Sabine Pass in MISO South

Historic Flow Patterns and LNG Imports

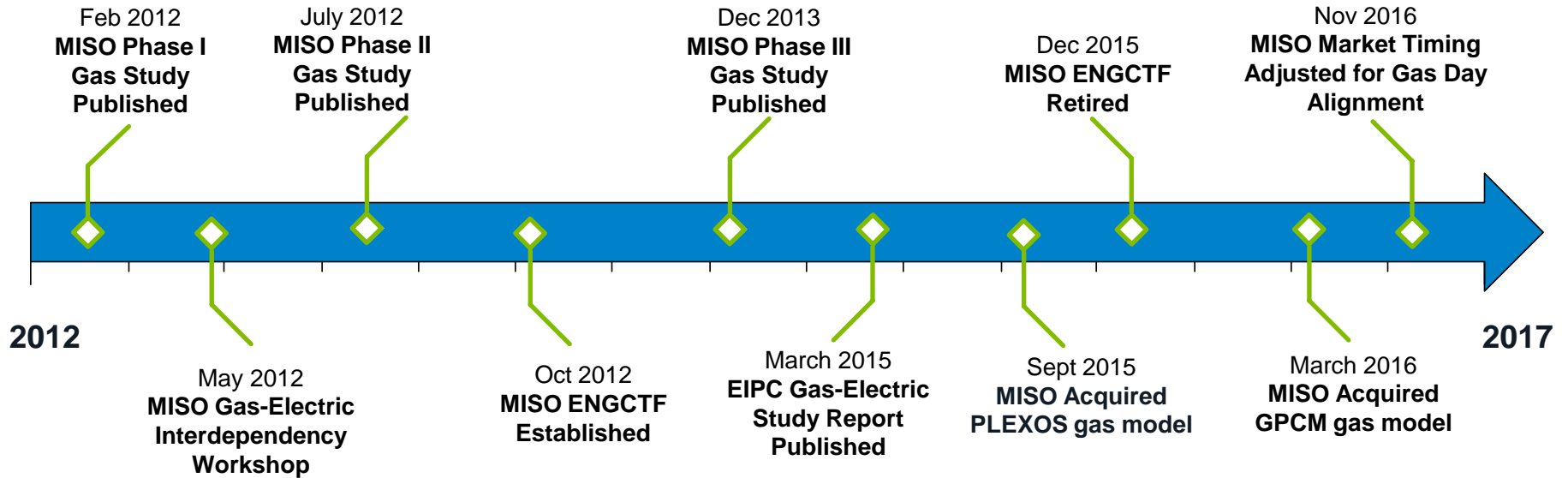


Developing "Grid" Flow Patterns & LNG Exports



Graphics per MISO Phase I: Gas and Electric Infrastructure Interdependency Analysis, February, 2012. Updated flow changes 2015

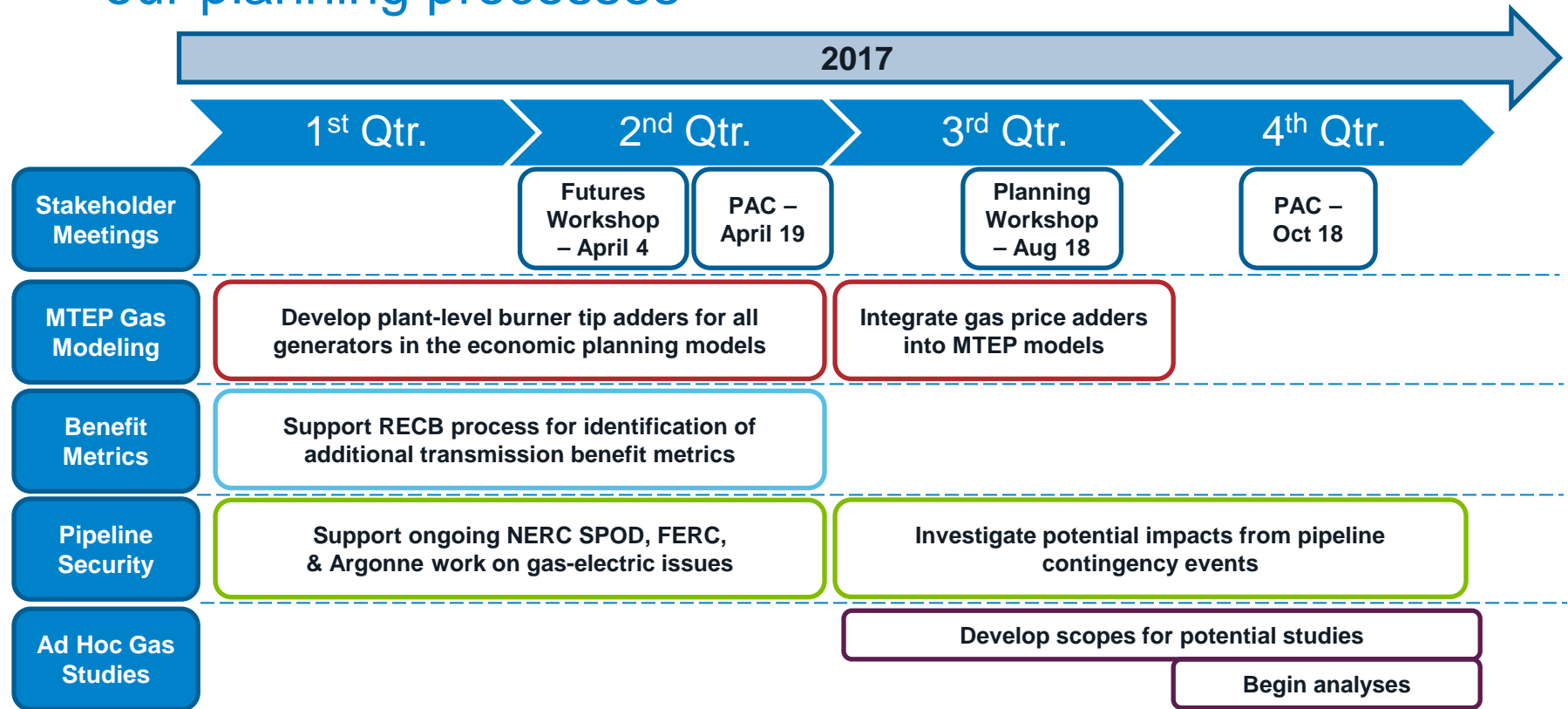
MISO has been working to understand the impacts of the evolving gas system for the past 6 years



MISO is supporting a number of external work efforts intended to investigate gas-electric reliability

- **2015 EIPC study investigated gas-electric contingency events**
 - MISO is supporting FERC in reviewing the results of the study and identifying critical areas of pipeline security
- **NERC transmission planning standards (TPL-001-4) came into effect 2015/2016**
 - MISO's Extreme Events reliability analysis includes "Loss of two [or more] generating stations resulting from...loss of a large gas pipeline into a region"
- **NERC Single Point of Disruption (SPOD) special assessment**
 - MISO is supporting NERC in the study that aims to identify potential risks to BPS as a result of disruptions on major natural gas infrastructure facilities
- **DOE/PHMSA Task Force – *Ensuring Safe and Reliable Underground Natural Gas Storage***
 - MISO is working with Argonne National Labs to identify large gas storage facilities where an outage could have an effect on gas-fired generation reliability

MISO is continuing to integrate our gas understanding into our planning processes





On-going Non-Planning Gas-Electric Items



MISO Operator Tools and Coordination with the Gas Industry

Questions to Answer

1. How do MISO system operators ensure reliable operations in regards to fuel availability challenges?
2. What initiatives has MISO Gas-Electric recently taken to promote reliability?
3. How does MISO work with the natural gas industry in order to foster coordination?

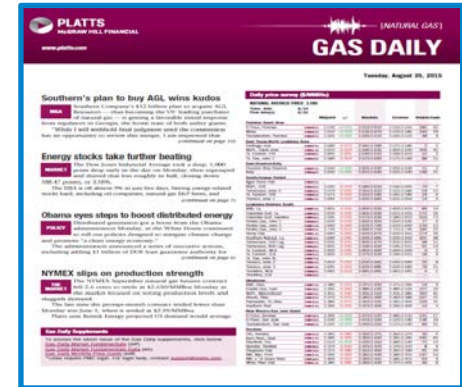
MISO Control Room Operations

- Commitments are based off market participant submitted unit parameters
- MISO expects market participants to update unit availability via the Market Portal
- MISO is not a direct customer of pipelines/LDCs and expects gas system operators to communicate directly with generators

MISO has improved communication & situational awareness around pipeline activities and impacts to generators

- Leveraging MISO Pipeline Notification Website
- Monitoring market conditions
 - Intercontinental Exchange (ICE), Platts, and Bentek Subscriptions
- Expanding control room tools & reports to improve visibility & awareness
- Expanding involvement in gas industry events and conferences

Orders	Deals	Options	UPS	Basis	Mid-Cont	West	Gulf	East	NYMEX	Balmo
<input type="checkbox"/> Hold Orders (inactive) <input type="checkbox"/> Live Only										
Product	Hub	Strip	RFQ	+	-	Sell	Qty	Bid		
NG Firm Phys, FP	Michcon	Same Day		+			1800	2.705		
NG Firm Phys, FP	NBPL-Ventura	NxDay Intra								
NG Firm Phys, FP	NGPL-Midcont Pool	Same Day		+						
NG Firm Phys, FP	NNG-Demarc	Same Day								
NG Firm Phys, FP	NNG-Ventura	Same Day								
NG Firm Phys, FP	Panhandle	Same Day		+						



MISO's Gas Pipeline Notifications Website provides regional insight into pipeline operating conditions

- Scrapes 35 MISO Pipeline EBB's for Critical Postings
- Useful for Market Participants and MISO Staff
- One Location, Regional Insight
- Critical Postings are issued if supply, capacity, or operational flexibility is impacted
- www.misoenergy.org > Markets and Operations > Gas Pipelines
 - <https://www.misoenergy.org/MarketsOperations/Pages/GasPipeline.aspx>

The screenshot displays the MISO website's 'Markets and Operations' section. A navigation menu includes 'Home', 'About Us', 'What We Do', 'Stakeholder Center', and 'Markets and Operations' (highlighted with a red circle). Below the menu, a sidebar lists 'Credit', 'Frequency Response', 'Gas Pipeline' (highlighted with a red circle), and 'Independent Market Monitor'. The main content area is titled 'Critical Pipeline Notifications' and contains a table with columns for Pipeline, ID, Type, and Update. A detailed view of a notice is shown in a pop-up window, providing specific details about a capacity reduction on the Southeast Mainline of the Southeast Control Pool.

Pipeline	ID	Type	Update
ANR	7491	Maint	Southeast Update (Manning)
ANR	7490	Maint	Capacity Update (Semina)
GSFC	5022193	Maintenance	Index 1
GSFC	5022192	Maintenance	Index 4
ANR	7489	Maint	Capacity 7/27/2015 (See CI)
NGPL	35476	Maintenance	Seg 28
GSFC	5022191	Maintenance	Index 3
GSFC	5022190	Maintenance	Terminate - Index 391 Maintenance (High Run (Longnose to Carriage))
TGP	356556	Other	Tgp Dart Update-Webex Reminder
TET	61529	Capacity Constraint	Ta Pipeline Conditions For 07/26/2015 Intraday

Critical Notice
 Notice Type: Maint
 Posting Date/Time: 07/27/2015 09:00
 Notice ID: 7491
 Notice Start/End Date/Time: 11/01/2015 08:39
 Notice ID: 7491
 Notice Status: Operate
 Price Notice: 5479
 Reg. Date/Time: 07/27/2015 09:00
 Reg. Date/Time: 07/27/2015 09:00
 Subject: Southeast Mainline Capacity Reduction (Updated 7/27/2015) Update: ANR has updated the restrictions for the Southeast Mainline of the Southeast Control Pool (See CI ID # 7491)
 Notice Text: Southeast Mainline Capacity Reduction (Updated 7/27/2015) This posting supersedes CI ID # 7491. Update: ANR continues planned and unplanned engine repairs and pipeline maintenance along its SEML on the Southeast Control Pool Segment (SE-2). Effective immediately, the capacity will be reduced as follows: SEML (North of Brownsville) (DR) (W 1260399) 300-3d5d5d4d (leaving 700-3d5d5d4d available) 7:27 - 8:31 300-3d5d5d4d (leaving 900-3d5d5d4d available) 9:1 - 10:31 Based on current nominations, it is anticipated that the above reductions will have no impact to services. This posting will be updated as more information becomes available. For any questions regarding nominations or scheduling, please call the ANR Home and Scheduling Hotline at 1-800-821-0287

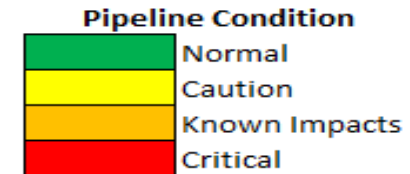
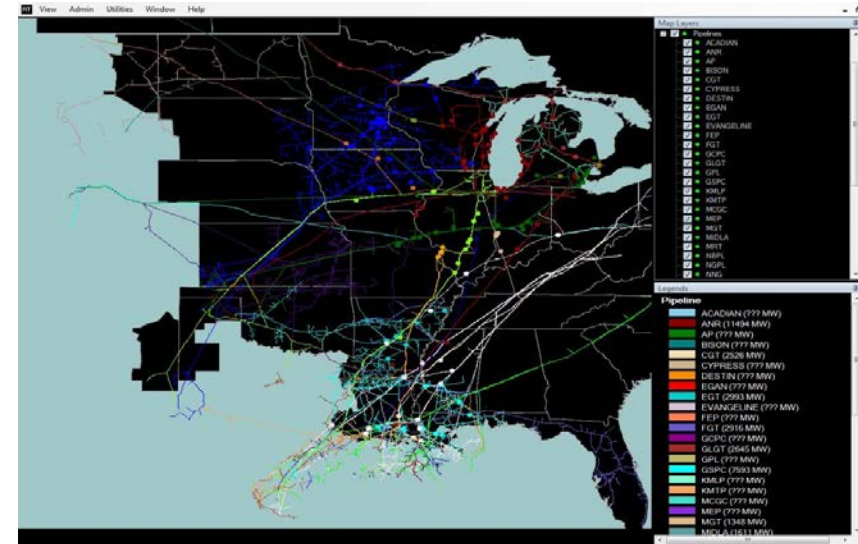
Fuel Impact Report: At Risk Units

- Internally, MISO will be monitoring the Pipeline Notification Website daily and will be translating relevant Critical Notices
- MISO will attempt to identify units that may be impacted and classify them as “At Risk” based on available information
 - Internal classification will not impact unit status or Market Participant’s portal submissions*

Generators with Potential Fuel Limitations*				Pipeline Notice - Unit Impact Report			
Pipeline	Condition	Unit	LBA/BA	Region	In Effect*	Notice	Potential Impacts / Reliability Note
PEPC Panhandle	Known Impact			Central	2/10-2/15	Cold Weather	Caution Units identified typically take fuel related outages on colder than normal days. Past availability has been in question. Confirmation of availability status is recommended.
MRT Mississippi River	Known Impact		Central	2/8- 2/15	System Protection Warning	Pipeline Flexibility Warning: Gas scheduling limitations on Generators Interruptible Transport may not flow. Generators may not be allowed to overburn; advance notice of dispatch may be needed	
NNG Northern Natural	Caution		North	2/12- 2/17	System Operating Limit	Flexible services have been allocated down by 50%. Units that did not clear but are dispatched RT, or units that receive extended runs may have limited availability	
NGPL Natural Gas Pipeline	Caution		Central	2/10-2/15	Capacity Limit	Limited Capacity - Interruptible Transport may be cut Interruptible Transport may not flow. Current posting targets Chicago area Generation, but units would benefit from advance notice of potential dispatch	

Control Room Electric/Gas Pipeline Real Time Display

- Further interpretation and leveraging of Pipeline Notification Website and Fuel Impact Report
- Pipeline Map Display with additional generator data included
- Daily interpretation of pipeline conditions
 - Pipeline Critical Notices will be translated and visually interpreted on display
 - Serves as quick reference for Operators
 - Provides visuals of restrictions
 - Improves situational awareness



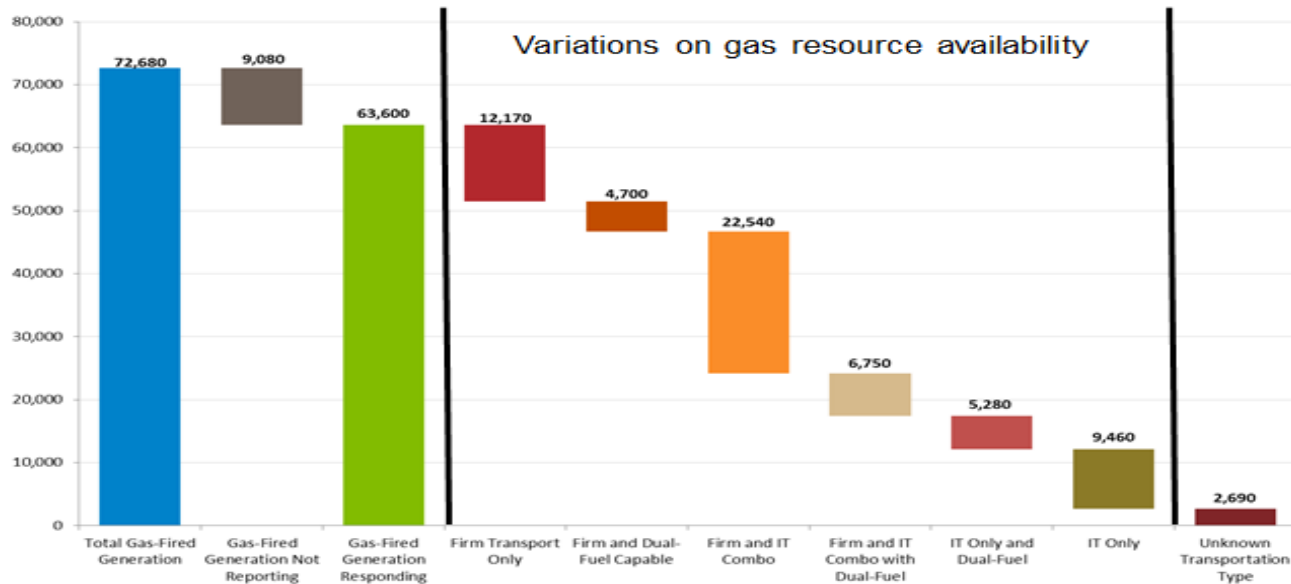
Gas Usage Profiles Project

- Gas system operators will receive customized daily summaries of usage forecasts based on the MISO day-ahead clearings of interconnected generators
 - Forecasted daily totals and hourly profiles
- MISO will coordinate with gas pipelines/Local Distribution Companies (LDCs) to develop the most effective gas usage aggregations for each system

Aggregation	24 Hours												Power Day Total
	0:00	1:00	2:00	...	6:00	7:00	8:00	9:00	10:00	11:00	...	23:00	
Agg1	-	-	-	...	-	2,202	2,228	2,202	2,440	2,202	...	2,540	38,033
Agg2	-	-	-	...	4,071	4,280	4,517	4,517	4,517	4,480	...	4,517	77,983
Agg3	-	-	3,539	...	7,724	7,790	8,111	8,060	8,093	8,106	...	3,541	140,653
Total	-	-	3,539	...	11,795	14,272	14,856	14,778	15,050	14,788	...	10,599	256,669

MISO 2017-2018 Winter Generator Survey

- October's survey will be MISO's 4th annual implementation
- Last year, MISO had its highest ever participation rate, with 87% (63,600 MW) of capacity reporting
- More user friendly for 2017, no significant changes to questions



Generator-Pipeline Database Upgrade

- Responsive to EOP-011, requested fuel characteristics for all MISO natural gas generators
- MISO now has complete database of pipeline connections and dual fuel capability for all gas generators
 - Further optimization of situational awareness tools

Asset Name	Power Plant Interconnect	Pipeline Interconnect (Inter/Intrastate)	Pipeline Meter	Secondary Fuel Capability
Name of the Combined Cycle [CC_XXXXXX]. This should be same as Combined Cycle Aggregate Name for Generator asset of each resource.	<i>Is your combined-cycle plant connected directly to a pipeline, LDC (local distribution company), or both Pipeline and LDC?</i>	<i>Select the Interstate or Intrastate pipeline(s) that connect to the generator (primary pipeline first, then subsequent pipelines). If not applicable, or source is not listed; Select "Not Applicable" or "Not Listed" and review subsequent fields.</i>	<i>Pipeline Meter Number (Used for nomination purposes) for each interconnect selected. List meter number for first pipeline selected, meter number for second pipeline selected, and so on. Separate with a comma.</i>	<i>Does the unit have Secondary (backup) fuel (YES/NO) ? Secondary fuel capability refers to ability to produce meaningful MW's, not just heating or auxiliary services.</i>
Unit 1	Pipeline	Enable	111111	No
Unit 2	Pipeline	NGPL	222222	No
Unit 3	Pipeline	Acadian Gas Pipeline, NNG	333333	Yes
Unit 4	Pipeline	ANR	444444	Yes

*Pipelines and services in this example are random and do not represent any actual MISO units

Gas Industry Outreach

- North American Energy Standards Board (NAESB)
 - Wholesale Gas Quadrant (WGQ) End User Segment
- Member of IRC Gas-Electric Task Force
- Monthly calls with G-E Operations Coordinators at other ISOs
- Monthly pipeline calls
- Pipeline/LDC visits and presentations
 - NGPL, NNG Pipeline, DTE Gas
- Presentations/workshops with state regulators (NARUC,OMS)
- Discussions with gas trade associations – INGAA (interstate pipelines), AGA (gas utilities), API (gas producers)
- Participation in various gas industry events and conferences

Questions?

Mark Thomas

Electric-Gas Operations Coordinator

mmthomas@misoenergy.org

317-249-4898



MISO Strategy and External Studies

Executive Summary



- Dependence on natural gas has implications for resilience and reliability
- MISO has made a number of preparations to minimize the impact of external events
- A changing fleet will stress the grid, but we will remain resilient and adapt

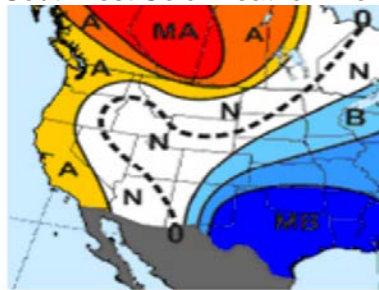
Events around the globe highlight the need to prepare for worst-case contingency events

Hurricane Katrina



2005

Southwest Cold Weather Event



2011

Aliso Canyon Gas Leak



2015

2008



Oil Pipeline Cyber-Attack in Turkey

2014



Polar Vortex

2016



South Australia Blackout

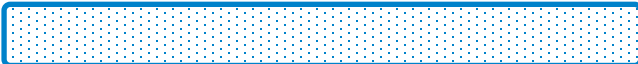
The gas industry operates to an entirely different reliability standard than the electric power industry



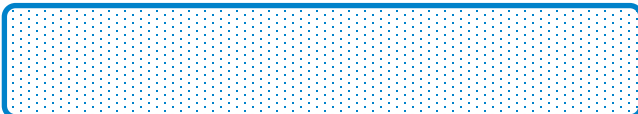
Natural Gas

Regulation: Transportation Security Administration (TSA) / FERC¹

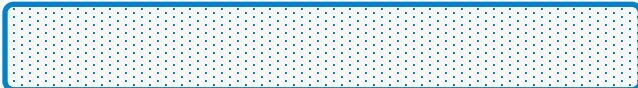
Standards: American Petroleum Institute / Pipeline and Hazardous Materials Safety Administration



Roles: Storage, Production, Pipelines, LDC



Standards: NAESB



Electric Power

Regulation: Federal Energy Regulatory Commission

Standards: North American Electric Reliability Corporation

Operator: Independent System Operator / Regional Transmission Organization

Roles: Generator Owner, Transmission Owner, Load Serving Entity

Guiding Principle: N-1 and N-X: BES will operate reliably over a range of probable contingencies. 1-in-10-year adequacy requirements

Standards: BAL-002-003, EOP-004-011, FAC-002-014, MOD-030, TPL-001-04

Unit loss

Line trip

Stuck breaker

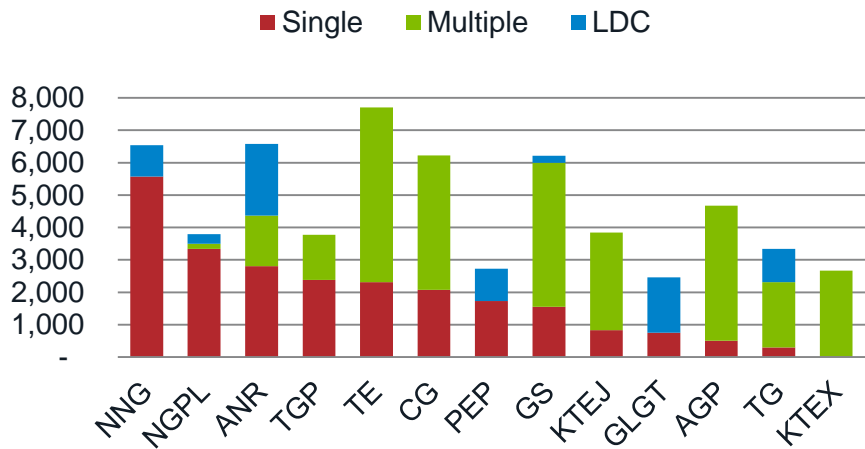
Station element failure

Load Loss

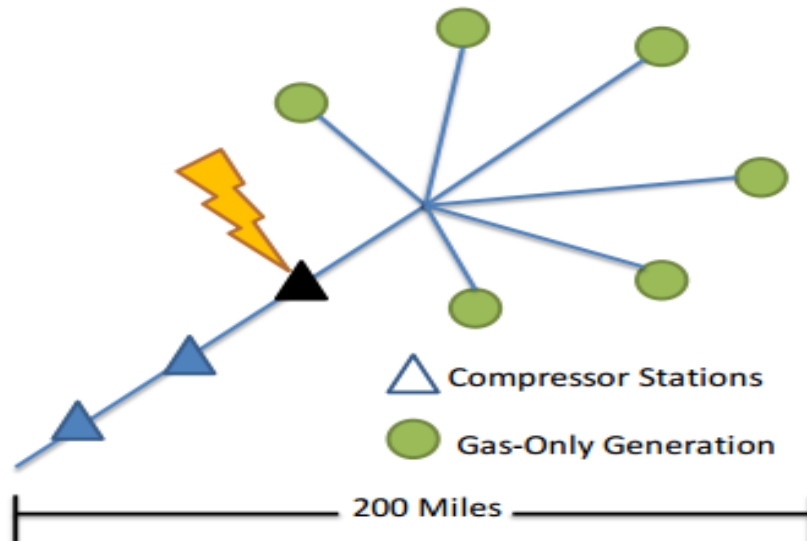
1) FERC reviews applications for construction and operation of natural gas pipelines – they have no jurisdiction over pipeline safety and security - TSA's responsibility

Gas-Electric interdependencies impact grid reliability and resilience

Installed Capacity (MW) vs. Pipelines¹



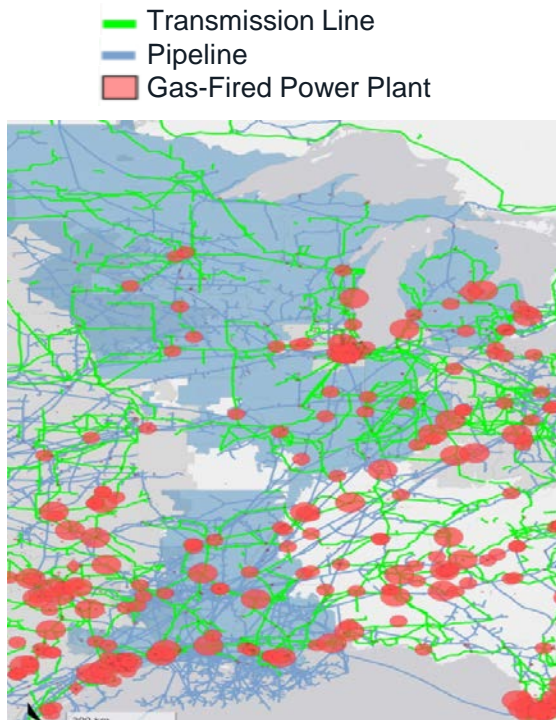
Compressor Failure Scenario



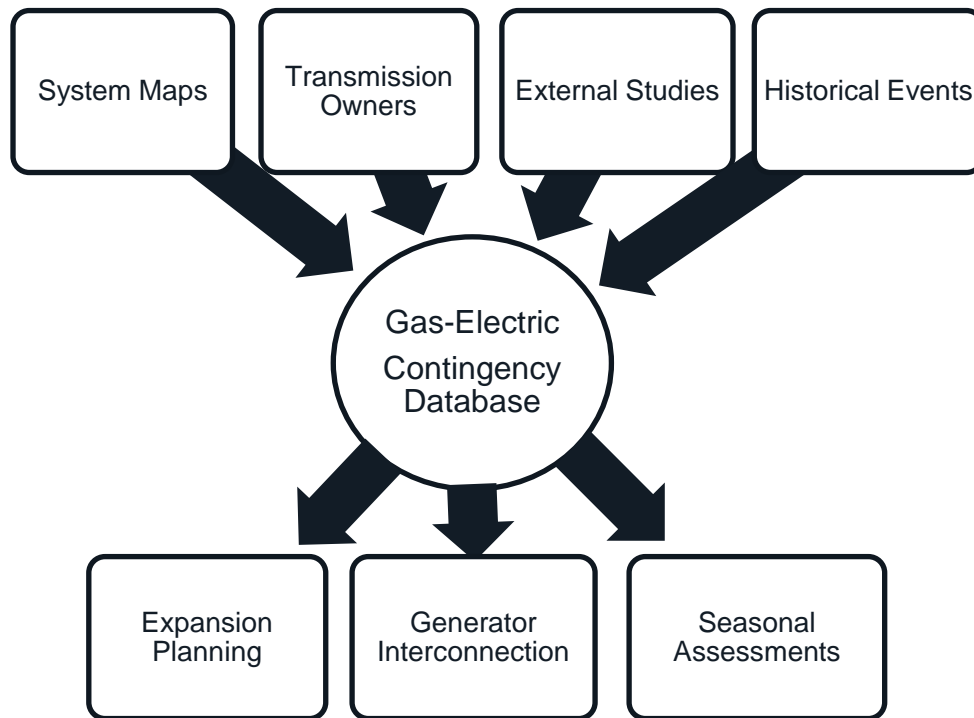
Source: NERC MRC Update on SPOD

1) LDCs may contain multiple interconnects

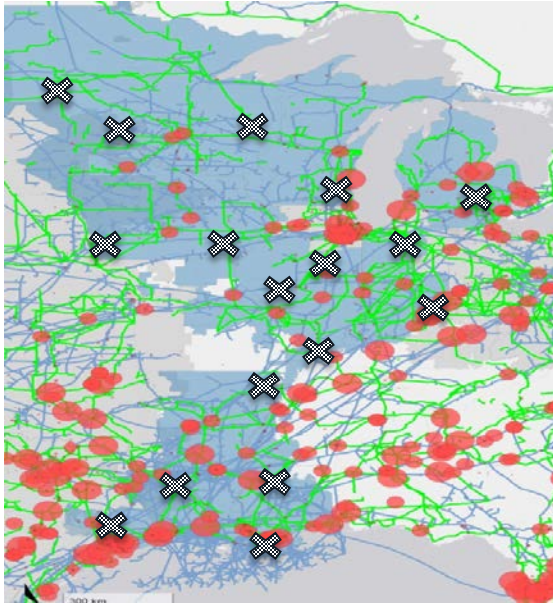
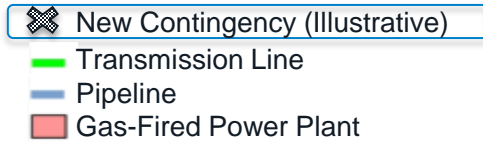
MISO's current process gathers gas pipeline events from a variety of sources, but does not capture all potential issues



Source: SNL Maps



MISO is leading a multi-year effort to improve risk awareness and increase resilience with increased gas-dependence



Source: SNL Maps

- The first phase (2018-2019) involves identification of potential system events
 - Where is the system at risk of an N-1 pipeline event becoming an N-x electric system event?
 - What are the time-domain impacts of these events?
- Later phases (2019 and beyond) will involve collaboration with stakeholders and the industry to understand and address any credible system risks
 - Are solutions needed on the electric system, the gas system, or both?
 - How can the electric industry ensure that the gas system is capable of meeting its needs?

Next Steps

- Continue revising scope and deliverables
- Update stakeholders and continue conversations at applicable forums (PAC, etc.)

Questions?

- How can MISO enhance bulk electric system reliability and resilience with increased gas dependence?

Contact:

Mike Nygaard – mnygaard@misoenergy.org

Kyle Abell - kabell@misoenergy.org

Jordan Bakke – jbakke@misoenergy.org



Introduction to GPCM

MISO is continuing to expand its ability to assess the interactions between the gas and electric systems

GPCM

About:

- Standalone natural gas model, built on MS Access database foundation
- Used for long-term look into pricing and pipeline flow trends

Pros:

- Well-regarded in gas industry
- Benchmarked against historical data
- Forecast dataset (included) is accurate and easily modified

Cons:

- Monthly data granularity
- No integrated electric model

PLEXOS

About:

- Co-optimized Gas/Electric production cost modeling platform
- Electric model has been used for many MISO studies, including CPP analysis

Pros:

- Capable of very granular detail
- Integrated gas/electric co-optimization
- Familiar tool for MISO

Cons:

- Minimal support for gas model
- No gas model dataset included

About the GPCM model

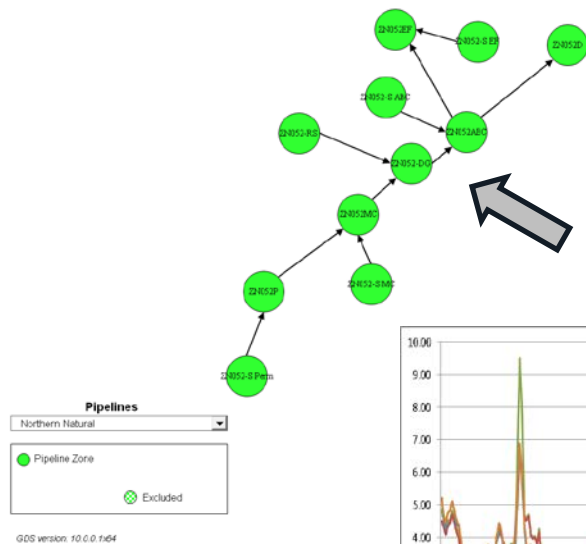
- RBAC Inc.'s Gas Pipeline Competition Model (GPCM) is a network flow model of the gas pipeline system in North America
 - Models over 1,000 pipeline nodes on 200+ interstate & intrastate pipelines
 - Includes all supply, demand, and storage information for the continent
 - Used to investigate the impacts of changes in supply, demand, and pipeline/storage infrastructure on prices and flow patterns
 - Includes historic data back to mid-2000s, and base forecasts through 2040
 - Used by a wide variety of gas & power industry organizations (midstream/upstream/downstream, consultants, national labs, banks)
 - More information: <https://rbac.com/gpcm-natural-gas-market-model/>

What can MISO do with GPCM?

- Incorporate assumptions from MTEP Futures on top of forecasts provided by RBAC (GPCM vendor)
- Adjust assumptions (supply, demand) to match gas price forecasts included in the MTEP Futures
- Output data provides a glimpse into flow patterns, basis differentials in various areas of the country, and potential infrastructure needs
 - Output data can also serve as an input to the PLEXOS model
- Quickly investigate the effects of major gas system changes on gas prices, flow patterns, and infrastructure needs.
 - Results of these quick-hit studies can be distilled into one-page reports for easy consumption

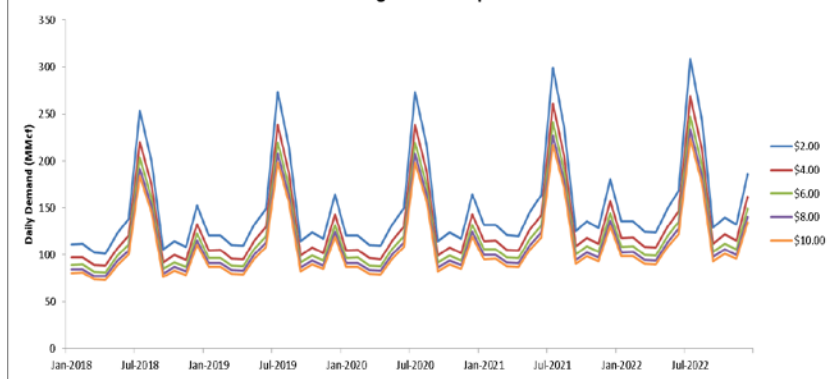
Sample of GPCM inputs and outputs

NORTHERN NATURAL MODEL

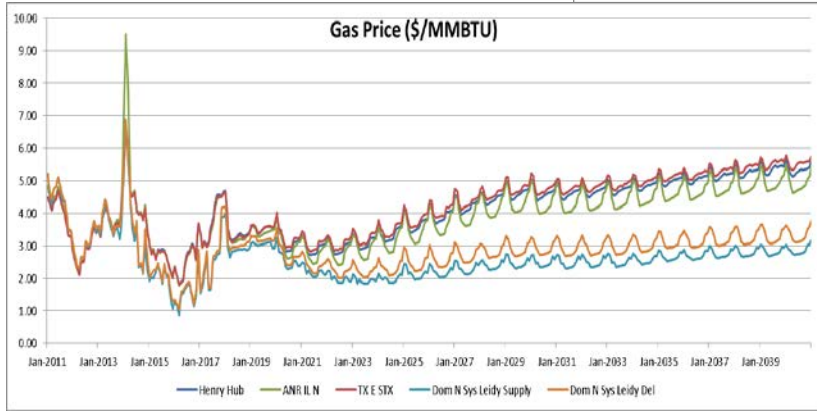


Each interstate pipeline is represented as a series of distinct pricing zones

Demand Curve Isograms - Sample ELC Customer



Demand (and supply) inputs are elastic curves, where total demand depends on price



GPCM calculates gas prices at Market Points and Pipeline Zones around the continent



Introduction to PLEXOS

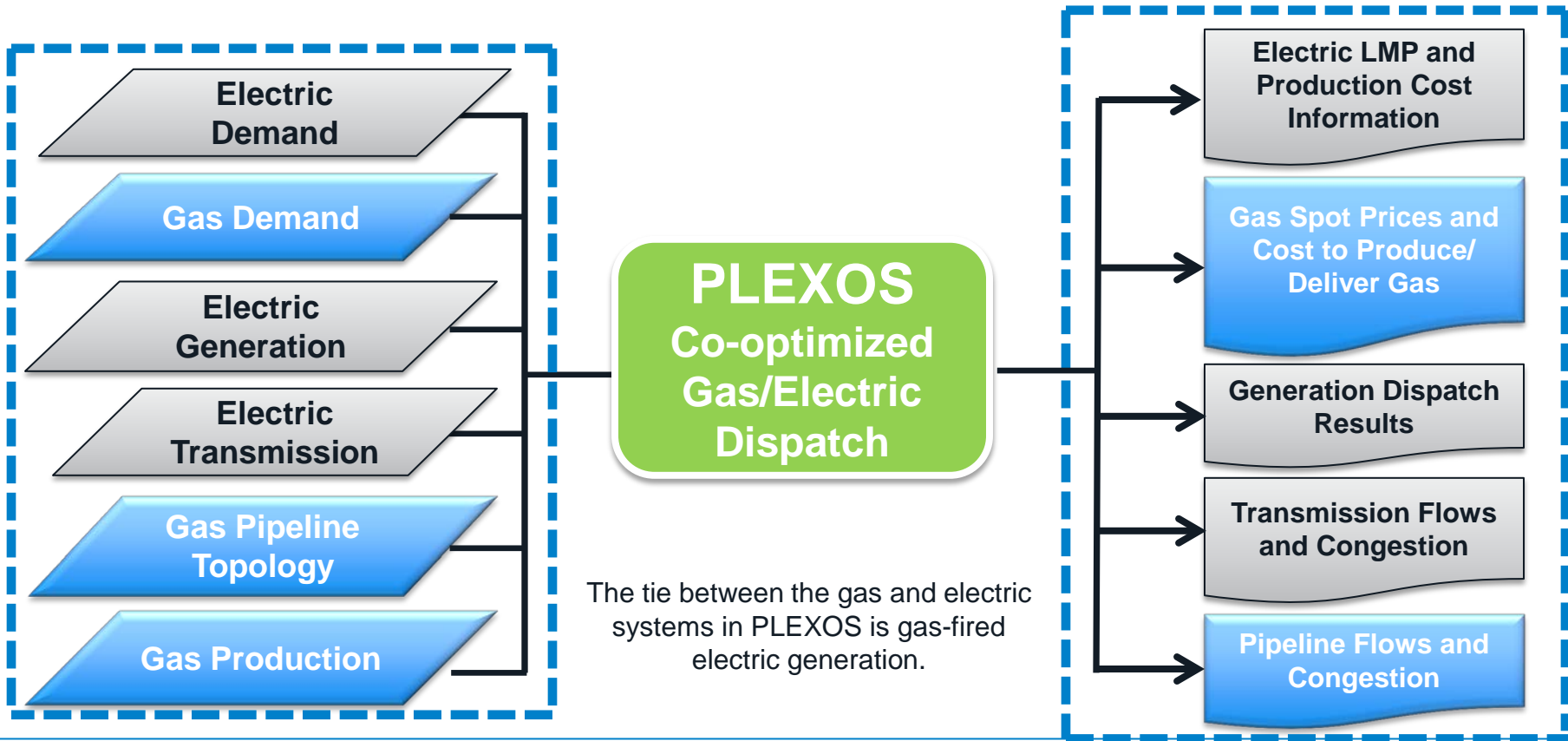
What is PLEXOS and why does MISO use it?

- A power market modeling and simulation software tool
- A flexible optimization platform with production cost modeling functionality
- Able to represent a variety of generation constraints, including rate-based emissions targets
- Able to simultaneously dispatch gas and electric systems

What is the PLEXOS integrated gas-electric model?

- It is the PLEXOS (electric) production cost model with built-in gas infrastructure
- It can simultaneously optimize gas and electric system operations in an hourly chronological dispatch
- It is an approximation of real-world gas and electric markets clearing in the same timeframe

High-level representation of PLEXOS gas-electric modeling

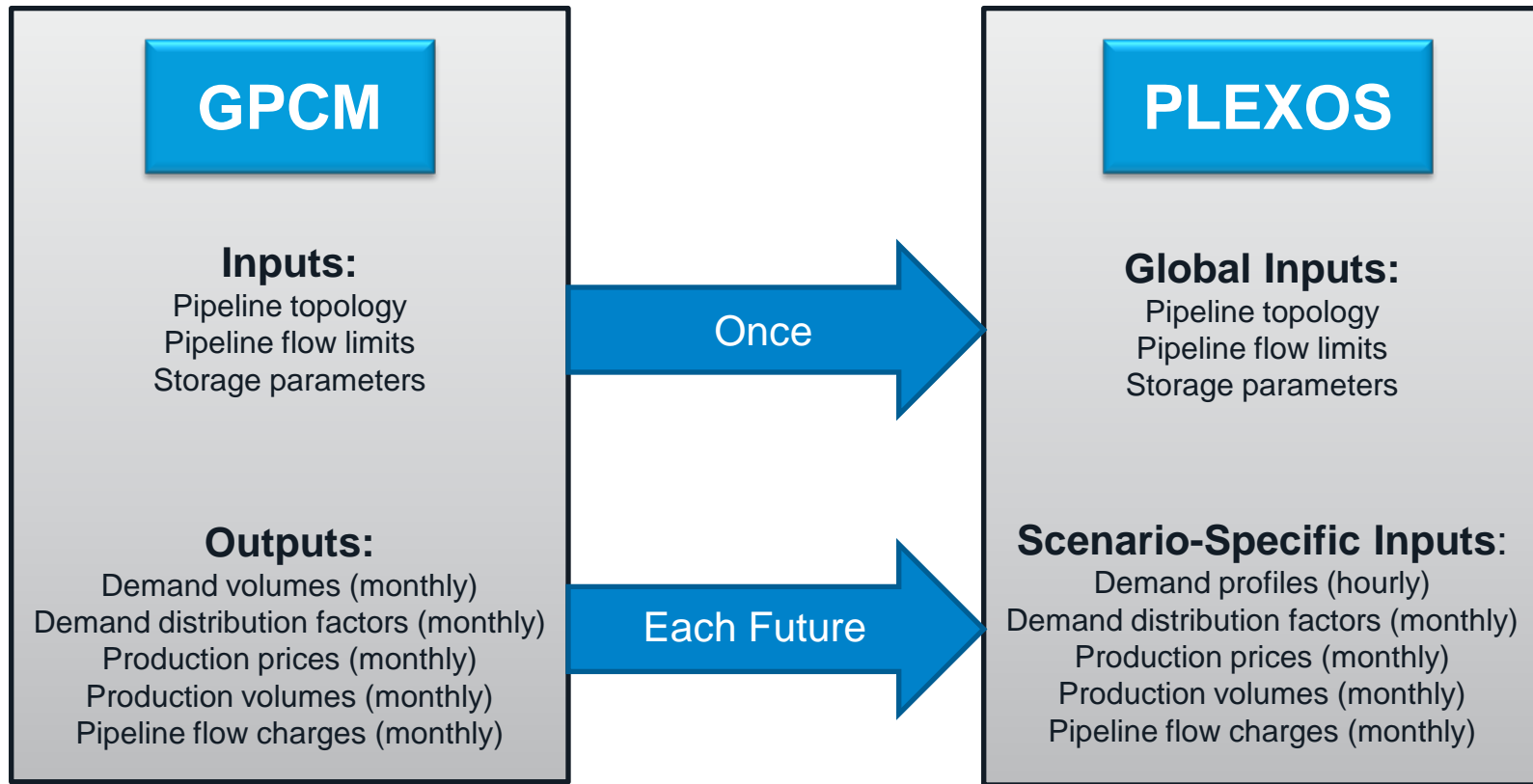


Representation of gas system topology parallels the electric system in PLEXOS

GAS INFRASTRUCTURE	In PLEXOS	ELECTRIC INFRASTRUCTURE
<p>Gas pipelines (incl. interstate, intrastate, laterals, headers, gathering)</p> <p>Min/max volume (MMcf), max flow (MMcf/d)</p>	<p>Lines</p>	<p>Electric transmission lines (≥ 34.5 kV)</p> <p>Min/max/overload ratings (MW), reactance (p.u.), resistance (p.u.)</p>
<p>Pipeline/pipeline or pipeline/load interconnects</p>	<p>Nodes</p>	<p>Electric buses</p>
<p>Gas basins/plays; gas storage fields</p> <p>Min/max production (MMcf); production price (\$/MMBtu)</p>	<p>Production/Source</p>	<p>Electric generators, demand-side management (DSM)</p> <p>Min/max capacity (MW); O&M (\$/MWh) and fuel price (\$/MMBtu)</p>
<p>Residential (R), commercial (C), industrial (I), power (gas-fired electric gen) loads; LNG exports</p> <p>Hourly profile per state for RCI; separate hourly profile for LNG; power load determined via PLEXOS (MMcf)</p>	<p>Demand/Sink</p>	<p>Residential, commercial, industrial loads</p> <p>Hourly profile per company (MWh)</p>

Note: This list is not exhaustive; additional characteristics are modeled for both the gas and electric systems.

GPCM to PLEXOS – Data hand-offs

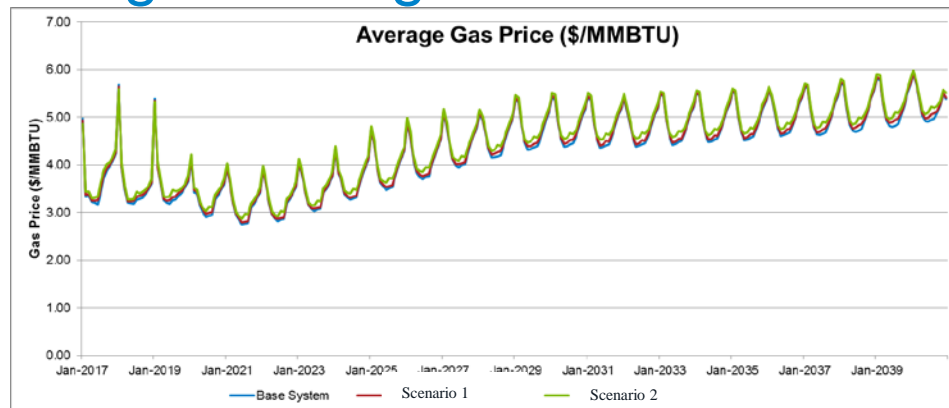


The PLEXOS integrated gas-electric model allows us to answer very complex questions

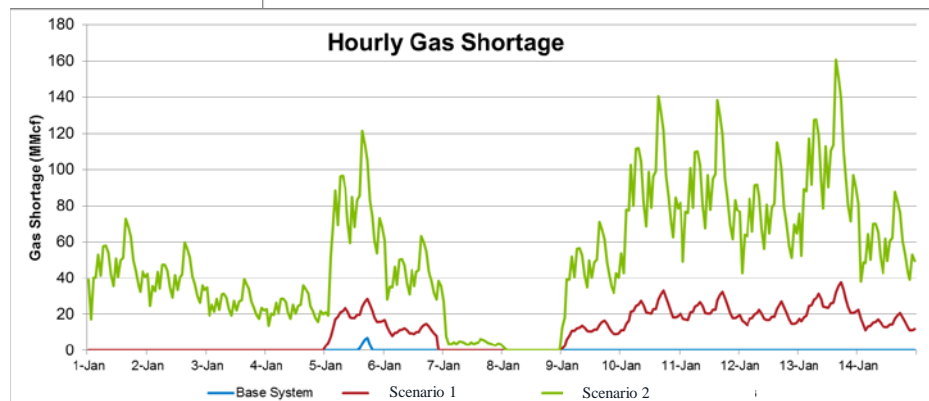
- Examples of potential study areas:
 - How would a major natural gas supply disruption (fracking ban?) affect the electric system?
 - How much additional generation can the existing gas pipeline system support before we see widespread congestion and price spikes?
 - How are ramping requirements affected by increased reliance on natural gas and renewables?
 - What new gas infrastructure will be needed in a future with more natural gas generation?

These models can tell stories about micro- and macro-effects of increased reliance on gas-fired generation

GPCM results highlight **long-term financial** impacts of increased gas usage



PLEXOS results highlight **operational and reliability** impacts of increased gas usage



*Charts are for illustrative purposes only



Gas Modeling in MTEP18

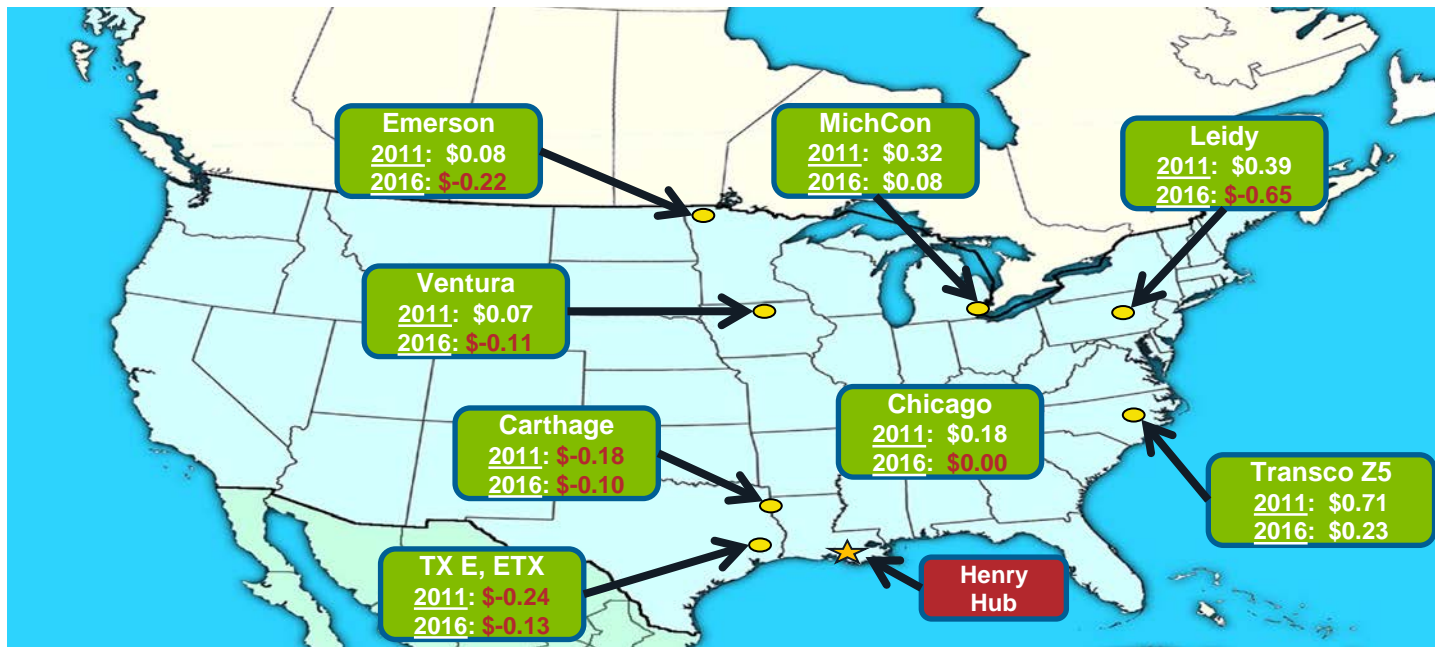
MISO's reliance on gas-fired generation continues to grow

- Natural gas generation has risen from 18% of MISO's energy in 2014 to 27% in 2016
- Nearly 8,000 MW of gas-fired generation projects in advanced stages of the GI queue¹
- MTEP17 futures built between 20,000 and 28,000 MW of additional gas-fired generation by 2031

1 - Generator projects in the DPP phase or with a signed GIA as of March, 2017

U.S. gas production from non-traditional supply regions is causing flatter national prices

- Increased flows to MISO from areas like Marcellus/Utica on new-build pipelines and pipeline reversals are improving MISO supply diversity



Market Point Price Basis: 2011 vs 2016

Copyright © 2000-2017 RBAC, Inc, All Rights Reserved

Powerbase's current representation of natural gas transportation is simplified

- Henry Hub gas price is developed through MTEP Futures process
- Fixed cost to transport gas from Henry Hub to one of a few dozen Market Points (Ventura, Carthage, Chicago, etc.)
 - Bases vary by month and year, **but not by Future scenario**
- Fixed cost to transport gas from Market Points to Natural Gas Pools (NG Indiana, NG Louisiana, NG Minnesota, etc.)
 - Intended to represent cost to get gas to a unit's "burner tip"
 - All generators in a pool see the same gas price

MISO has developed more granular gas prices for use in the MTEP study process

$$\text{Plant's Gas Price} = (\text{Locational Price}) + (\text{Burner Tip Price Adder})$$

- DOES NOT replace the Henry Hub price forecasting done as part of the MTEP18 Futures Development process
- Enables locational fuel prices to vary based on MTEP Futures assumptions (“Locational Prices”)
 - For example, increased industrial production along the Gulf Coast in the Limited Fleet Change future will cause higher relative gas prices in this region compared to the rest of MISO
- Allows for a more accurate representation of differences in fuel contracting costs (“Burner Tip Costs”)
 - Captures differences in costs for firm vs interruptible service, LDC connection vs direct pipeline connection
- Feedback on these changes was solicited through the MTEP18 Futures Development Workshop¹

¹ – See: <https://www.misoenergy.org/Events/Pages/FuturesDevelopmentMTEP1820170404.aspx>

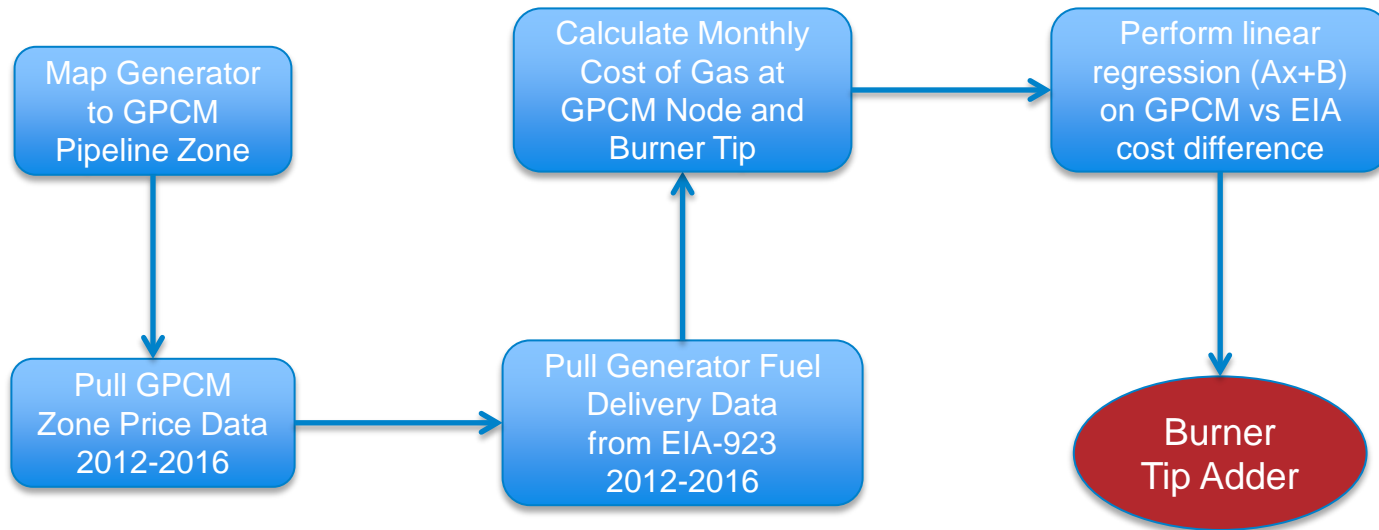
How are we doing Locational Prices? GPCM

- RBAC Inc.'s GPCM¹ is a network flow model of the gas pipeline system in North America. Gas prices are an output of GPCM
- We can model MTEP futures assumptions (supply/demand trends) in GPCM to develop gas price basis for each pipeline node in each future
- Units from the PROMOD model can be tagged to specific nodes on their supply pipeline

How are we doing Burner Tip Costs? EIA-923

- EIA-923 Power Plant Operations Report collects information on fuel cost for power plants
 - Monthly data includes total delivered volume of natural gas, and price in average \$/MMBTU
 - Price reflects all-in cost for generators to procure fuel (e.g. fixed service charges, variable commodity charges)
- We plot the delivered volume against the cost difference between the burner tip and the GPCM node. Linear regression gives an approximation of the variable cost component
- RRF units (and any other missing units) will be given a burner tip cost consistent with units of the same type in the same county (or state, where county is not available)
- Burner tip costs are assumed to not change considerably over the course of the study period or by future scenario

The process for developing individual burner tip adders requires data from multiple sources



Step 1 - Map Generator to GPCM Pipeline Zone

Angus
Anson



In the MISO Commercial Model, Angus Anson lists a connection to Northern Natural pipeline. Anson is in Northern Natural's "Market ABC" Zone

Step 2 - Pull GPCM Zone Price Data 2012-2016

Pipeline Zone Price and Basis				
Zone	Period	Fcst Zone Use	Fcst Rcpt Pt Price	
NNG Mkt ABC				
NNG Mkt ABC	Jan-2012	960	\$2.937	
NNG Mkt ABC	Feb-2012	881	\$2.742	
NNG Mkt ABC	Mar-2012	933	\$2.337	
NNG Mkt ABC	Apr-2012	930	\$2.155	
NNG Mkt ABC	May-2012	869	\$2.551	
NNG Mkt ABC	Jun-2012	798	\$2.524	
NNG Mkt ABC	Jul-2012	820	\$3.009	
NNG Mkt ABC	Aug-2012	833	\$2.929	
NNG Mkt ABC	Sep-2012	845	\$2.932	
NNG Mkt ABC	Oct-2012	849	\$3.411	
NNG Mkt ABC	Nov-2012	1,005	\$3.709	
NNG Mkt ABC	Dec-2012	938	\$3.451	

GPCM's historic data gives wholesale gas prices for each pipeline zone dating back to the mid-2000s

Step 3 - Pull Generator Fuel Delivery Data from EIA-923 2012-2016

YEAR	MONTH	Id	Plant Name	State	FUEL_GROUP	SUPPLIER	QUANTITY	FUEL_COST	Operator Name
2012	1	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	1,148.0	\$ 5.60	Northern States Power Co - Minnesota
2012	2	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	2,078.0	\$ 5.11	Northern States Power Co - Minnesota
2012	3	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	885.0	\$ 4.02	Northern States Power Co - Minnesota
2012	4	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	13,872.0	\$ 2.98	Northern States Power Co - Minnesota
2012	5	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	63,651.0	\$ 3.41	Northern States Power Co - Minnesota
2012	6	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	162,684.0	\$ 3.30	Northern States Power Co - Minnesota
2012	7	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	881,596.0	\$ 3.23	Northern States Power Co - Minnesota
2012	8	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	186,318.0	\$ 3.79	Northern States Power Co - Minnesota
2012	9	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	34,940.0	\$ 4.86	Northern States Power Co - Minnesota
2012	10	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	37,210.0	\$ 6.01	Northern States Power Co - Minnesota
2012	11	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	5,870.0	\$ 4.43	Northern States Power Co - Minnesota
2012	12	7237	Angus Anson	SD	Natural Gas	VARIOUS (NATURAL GAS SPOT PURCHASES ONLY)	188.0	\$ 3.93	Northern States Power Co - Minnesota

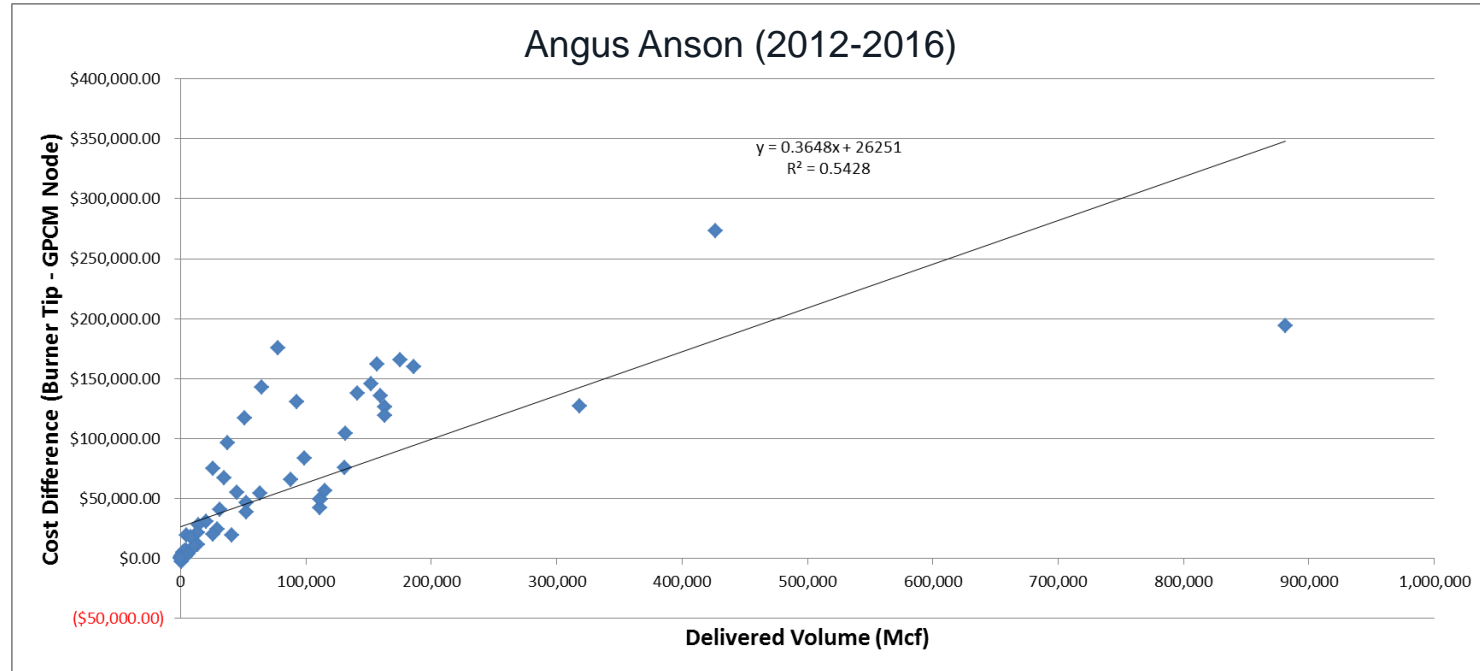


The EIA-923 Power Plant Operations Report gives all-in fuel cost and delivered volume for each US power plant

Step 4 - Calculate Monthly Cost of Gas at GPCM Node and Burner Tip

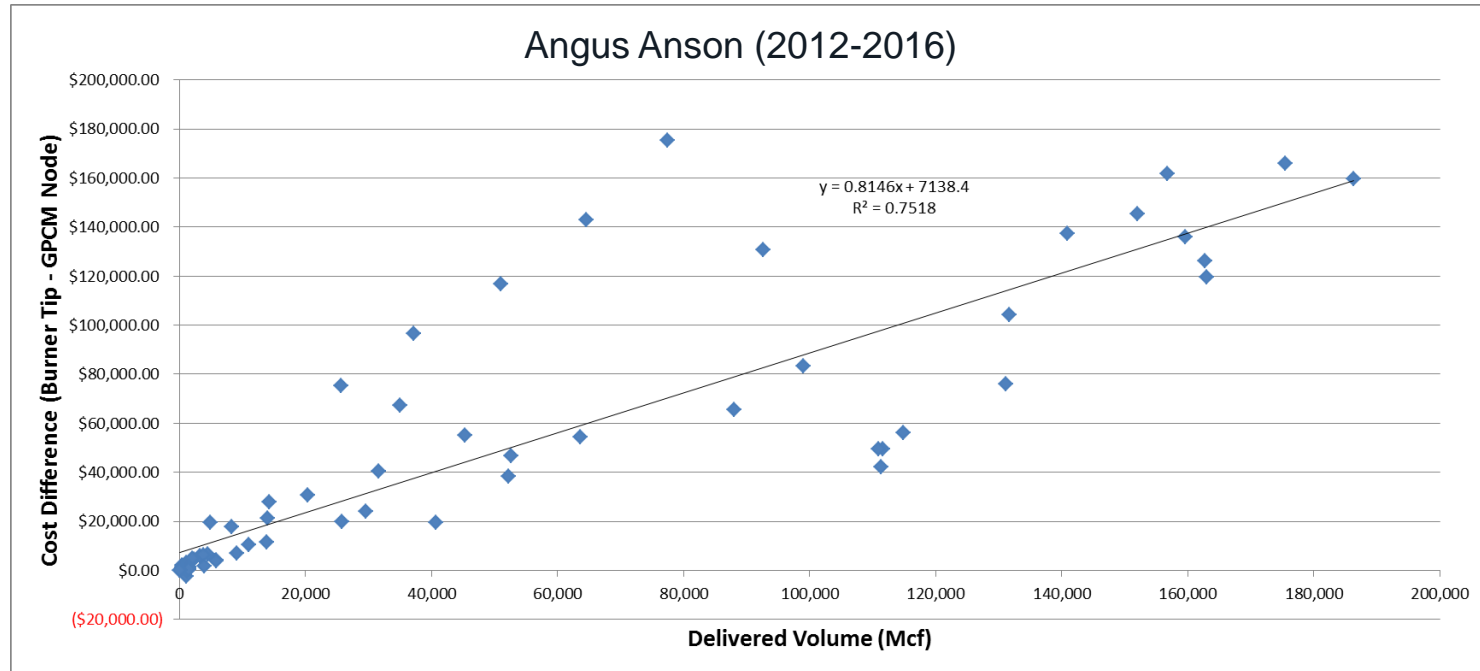
Year	Month	Total Delivery (Mcf)	EIA Avg Price	EIA Total Cost (EIA Price x EIA Volume)	GPCM Avg Price	GPCM Total Cost (GPCM Price x EIA Volume)	Total Cost Difference (EIA Cost - GPCM Cost)
2012	1	1,148	\$ 5.60	\$ 6,427.65	\$ 2.94	\$ 3,375.12	\$ 3,052.53
2012	2	2,078	\$ 5.11	\$ 10,626.89	\$ 2.74	\$ 5,693.72	\$ 4,933.17
2012	3	885	\$ 4.02	\$ 3,556.82	\$ 2.34	\$ 2,070.90	\$ 1,485.92
2012	4	13,872	\$ 2.98	\$ 41,310.82	\$ 2.15	\$ 29,824.80	\$ 11,486.02
2012	5	63,651	\$ 3.41	\$ 216,858.96	\$ 2.55	\$ 162,310.05	\$ 54,548.91
2012	6	162,684	\$ 3.30	\$ 536,694.52	\$ 2.52	\$ 409,963.68	\$ 126,730.84
2012	7	881,596	\$ 3.23	\$ 2,846,673.48	\$ 3.01	\$ 2,653,603.96	\$ 193,069.52
2012	8	186,318	\$ 3.79	\$ 705,399.95	\$ 2.93	\$ 545,911.74	\$ 159,488.21
2012	9	34,940	\$ 4.86	\$ 169,703.58	\$ 2.93	\$ 102,374.20	\$ 67,329.38
2012	10	37,210	\$ 6.01	\$ 223,594.89	\$ 3.41	\$ 126,886.10	\$ 96,708.79
2012	11	5,870	\$ 4.43	\$ 25,974.75	\$ 3.71	\$ 21,777.70	\$ 4,197.05
2012	12	188	\$ 3.93	\$ 738.46	\$ 3.45	\$ 648.60	\$ 89.86

Step 5 - Perform linear regression (Ax+B) on GPCM vs EIA cost difference



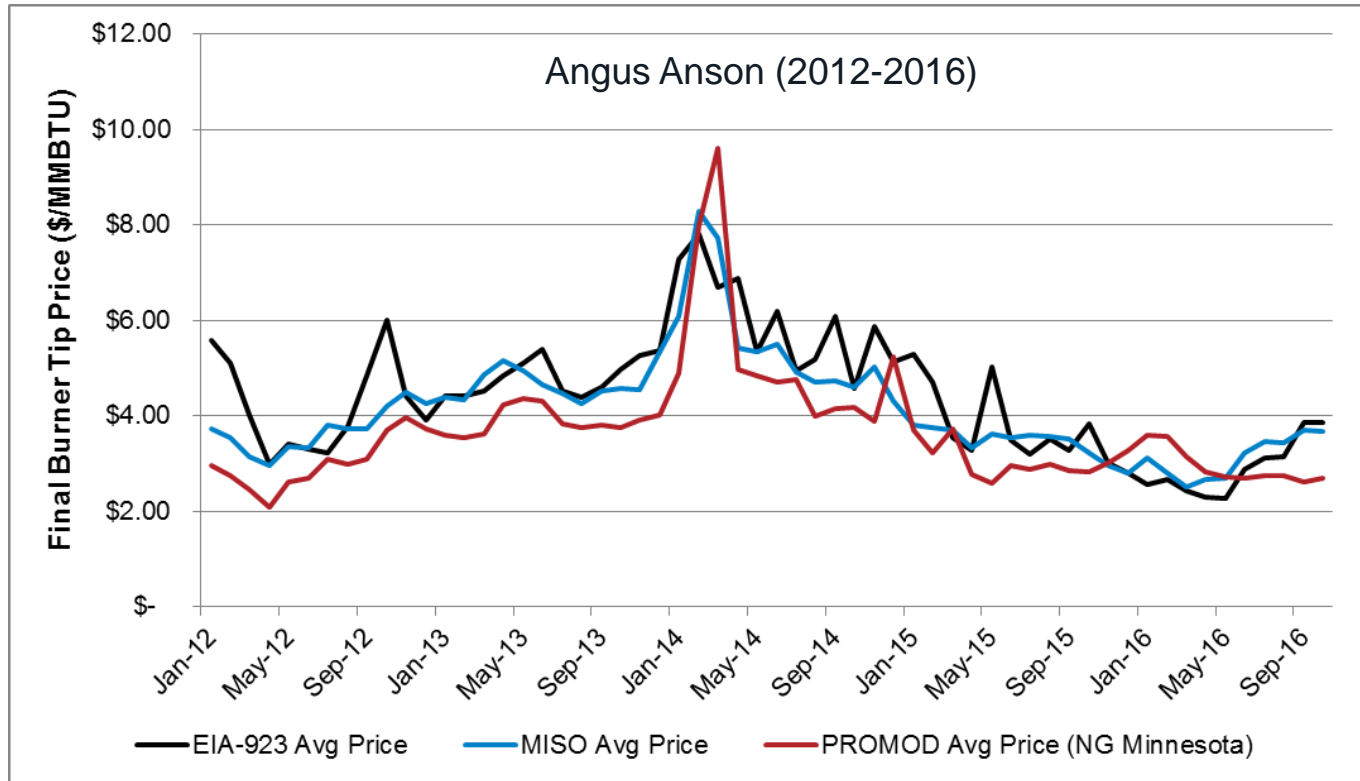
Three data points are very obvious outliers, more than two standard deviations away from the median delivered volume.

Step 5 - Perform linear regression (Ax+B) on GPCM vs EIA cost difference – **NO OUTLIERS**

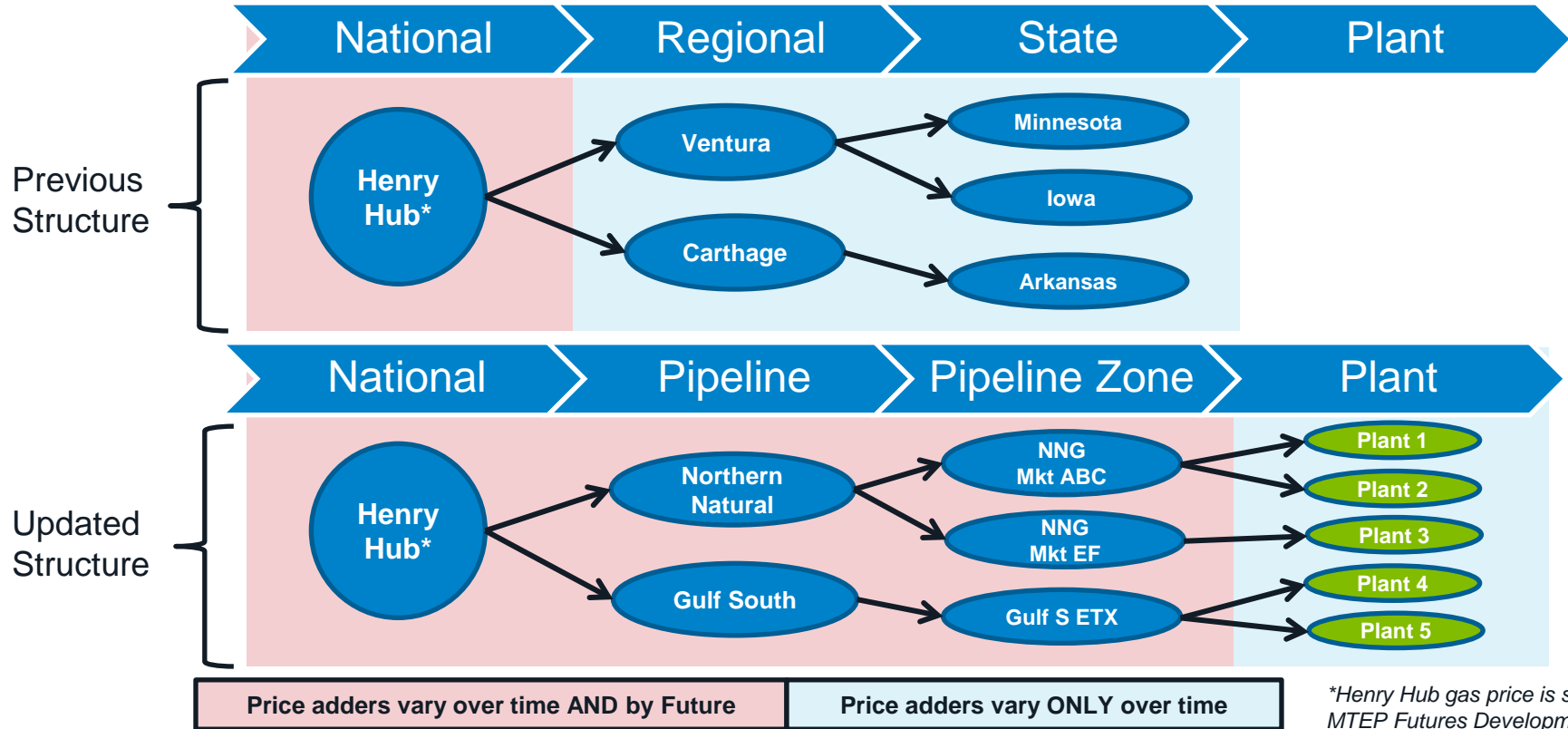


Removing these outliers creates a much closer trend line. The variable component of this line is the burner tip adder, \$0.8146/MMBTU

The result is a unit-specific gas price that reflects market data better than that generated by PROMOD



MISO's enhanced gas modeling provides more granularity, accuracy, and flexibility to locational gas prices



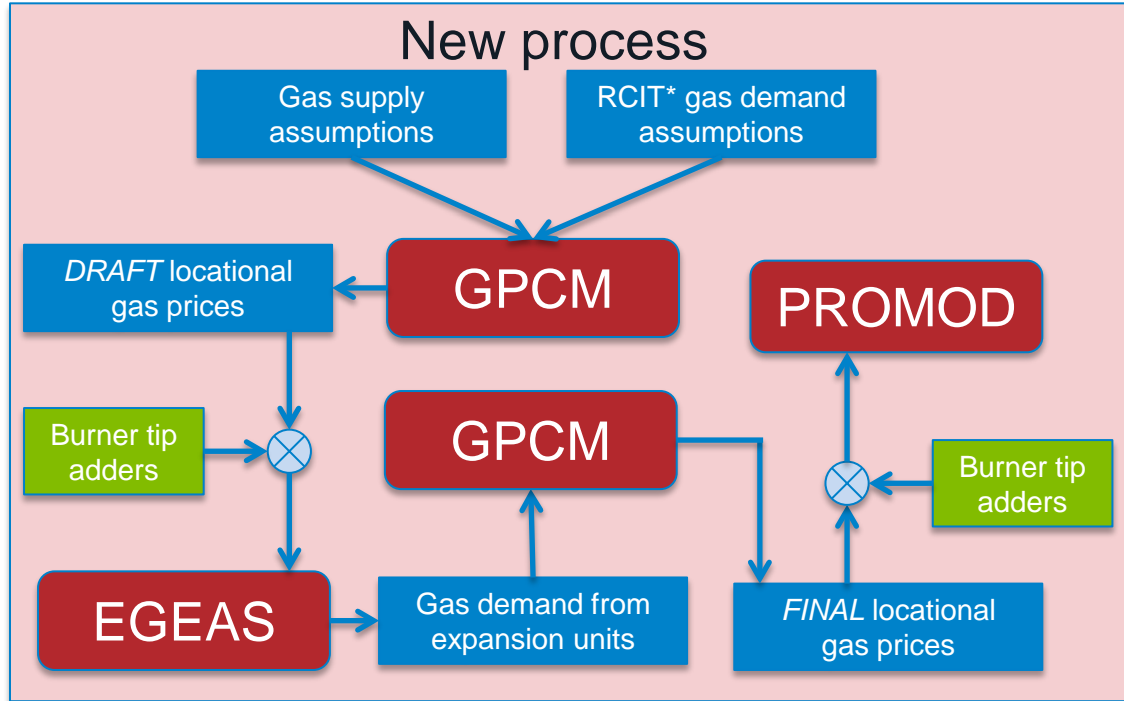
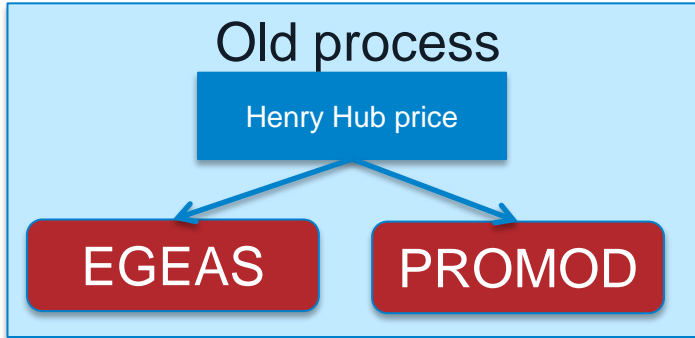
PROMOD 2013 Market Benchmark Testing

- Utilized new gas transportation system on the 2013 PROMOD Market Benchmark model
- Monthly burner-tip gas prices from this method were on average 1-3% higher than prices in the original PROMOD Benchmark model
- Gas-fired dispatch decreased slightly, to a level that more closely matches actual 2013 market trends
- LMPs in Illinois, Indiana, and Minnesota increased very slightly, to a level that more closely matches actual 2013 market trends

MISO released a Whitepaper in May 2017 that detailed this process, along with the benchmark results

<https://www.misoenergy.org/Events/Pages/PAC20170517.aspx>

MISO's new process models the impacts of our study assumptions on the gas pipeline system



	Old Process	New Process
Generator Pricing Points	33 (statewide pools)	~750 (One for each gas-fired plant in the model footprint)
Gas System Variables	Henry Hub price	Henry Hub price, gas supply & demand, pipeline congestion charges, fuel contract types

*RCIT: Residential, Commercial, Industrial, & Transportation (all demand except Electric Generation)

Why is this better than what we had?

- Instead of 24 natural gas market points and 33 state-wide natural gas pools, we can use hundreds of pipeline nodes with each plant possessing its own burner tip price adder
- More accurately reflects the nuances in different generators' fuel supply arrangements
- Allows for variation in regional gas prices as a result of MTEP futures assumptions
 - For example, increased industrial production along the Gulf Coast in the Limited Fleet Change future will cause higher relative gas prices in this region compared to the rest of MISO

Next Steps

- Support inclusion of these plant-specific gas prices in MTEP18 EGEAS & PROMOD models

Questions?

Contact:

Mike Nygaard –
mnygaard@misoenergy.org

Temujin Roach –
troach@misoenergy.org

Jordan Bakke –
jbakke@misoenergy.org



Walkthrough of Gas Price Forecasting with GPCM

Testing the sensitivity of gas prices to production shifts

- Developments in hydraulic fracturing and horizontal drilling have led to a wave of natural gas production from non-traditional regions of the US
- North Dakota's oil fields are rich in natural gas, which makes for a low-cost gas supply to much of MISO's North/Central region
- Due to a lack of outlet capacity, North Dakota's gas flaring rate peaked at 36% in January 2014.
 - Thanks to new gathering and processing capacity—and drops in production—flaring is currently down to around 12%
- Oil production in the region peaked in 2014 amid falling global oil prices. However, production can ramp up quickly if oil prices rebound

What happens if we cut Bakken production in half from 2027-2028?

Questions? Comments?

What else would you like to see come from this gas-electric modeling work? Ideas for interesting study topics? Other comments on approach?

General Questions:

Jordan Bakke – jbakke@misoenergy.org

Modeling Questions:

Mike Nygaard – mnygaard@misoenergy.org

Temujin Roach – troach@misoenergy.org



Appendix: Example results from GPCM run

Testing the sensitivity of gas prices to demand shifts

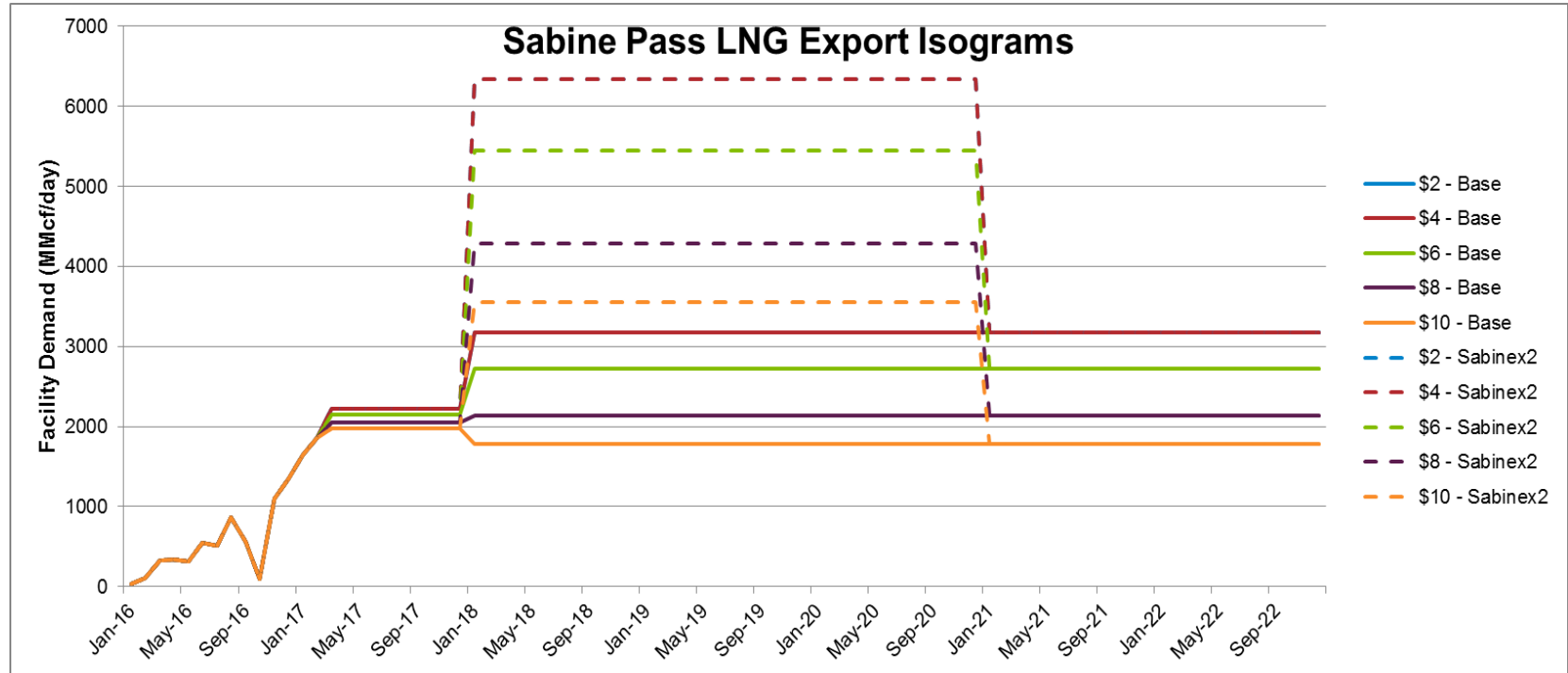
- The US is expected to become a net exporter of natural gas this year¹
- Sabine Pass is the first major Liquefied Natural Gas (LNG) export facility in the Lower 48 States, and is the single largest gas user in the country
- Three trains are currently online, with three more permitted. Two of which are currently under construction
- The expected export capacity of the facility upon completion of all trains is 27 million metric tons per annum (MTPA)
- An additional 50 MTPA of export capacity is under construction in the Gulf, with 35 MTPA more permitted²

What happens if we double Sabine Pass exports from 2018-2020?

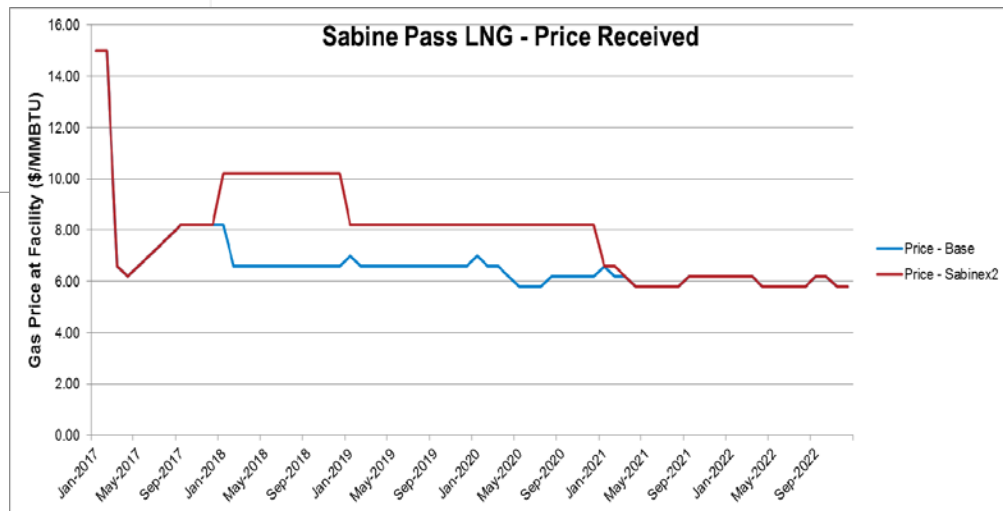
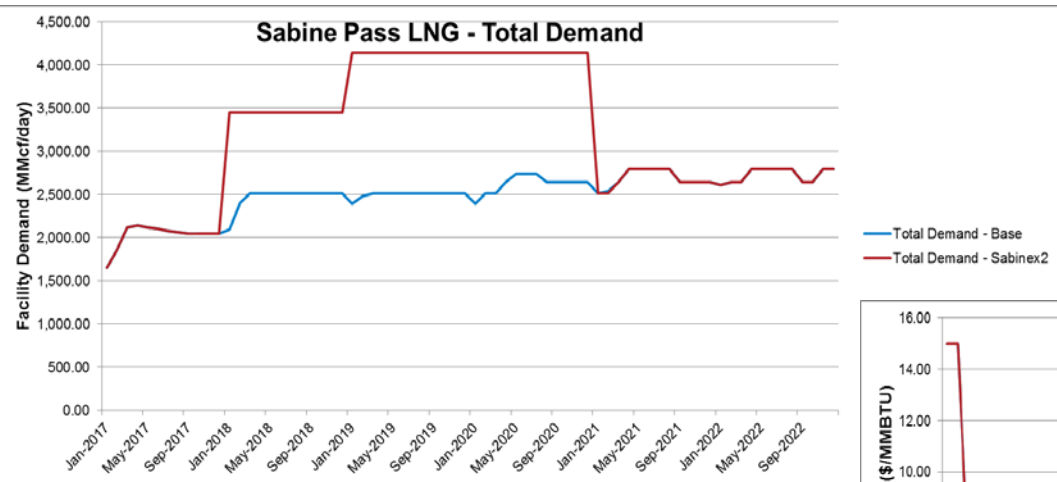
1 - <https://www.eia.gov/todayinenergy/detail.php?id=32412>

2 - <https://www.ferc.gov/industries/gas/indus-act/lng/lng-approved.pdf>

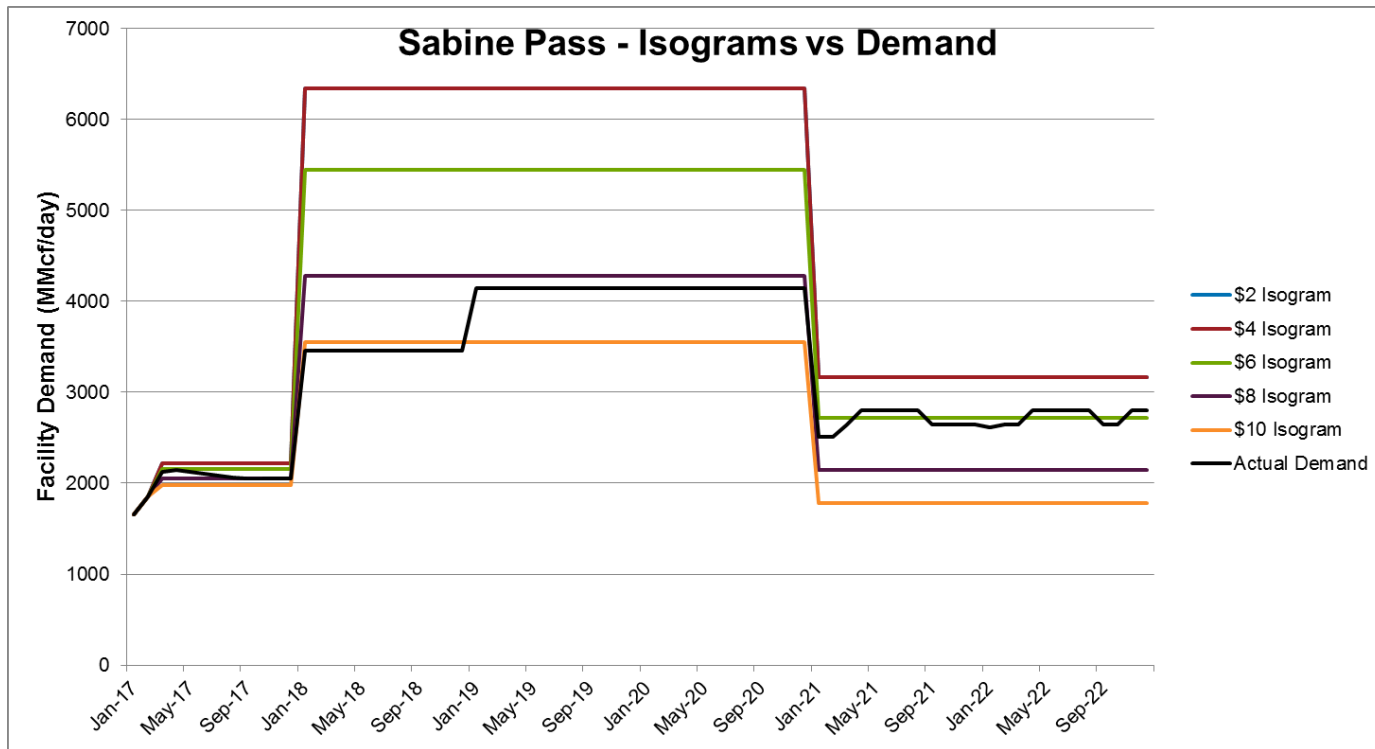
Isograms represent the demand from a customer given a fixed price of natural gas. In this example, demand saturates after \$4 (capacity of the facility is reached)



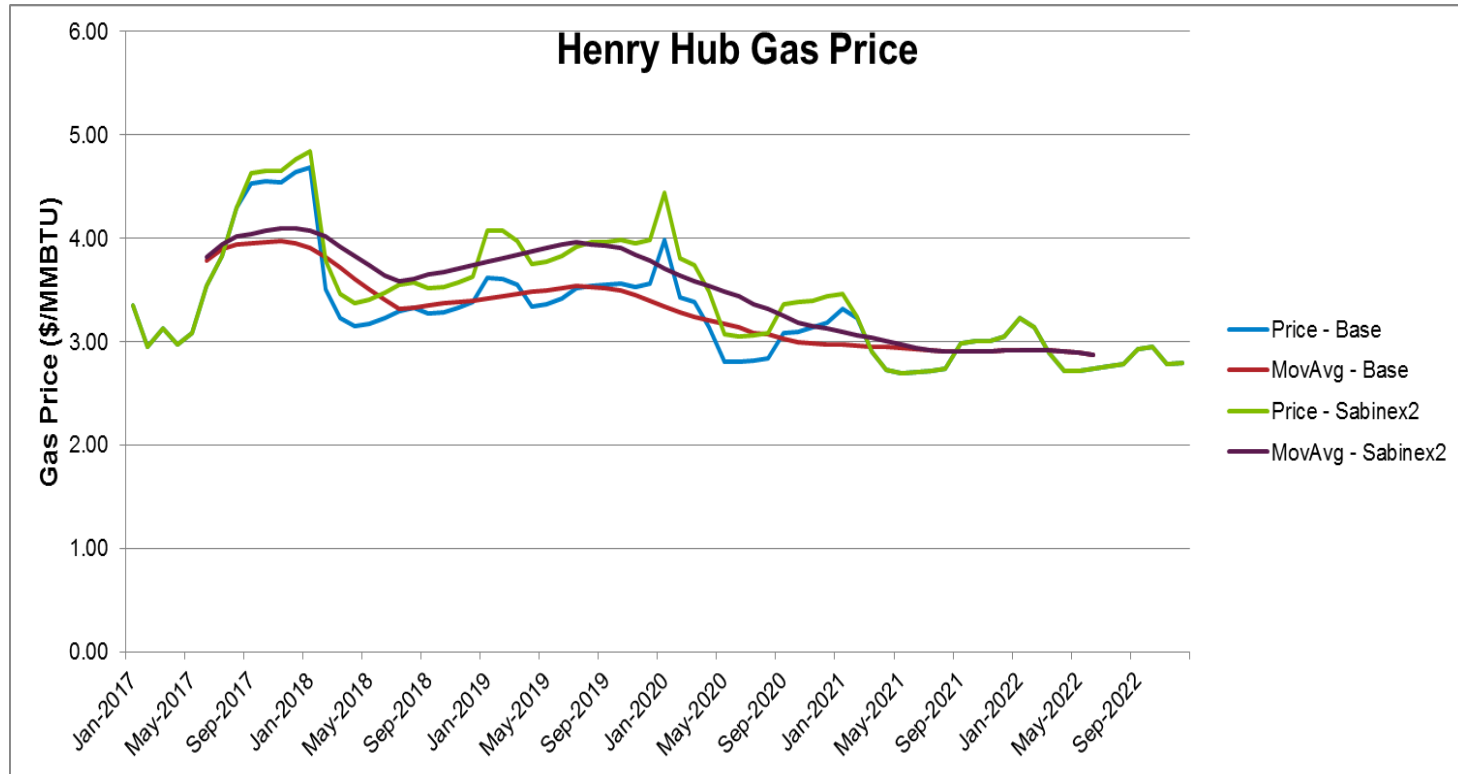
Total demand from a customer is a function of the price that the customer receives in the model



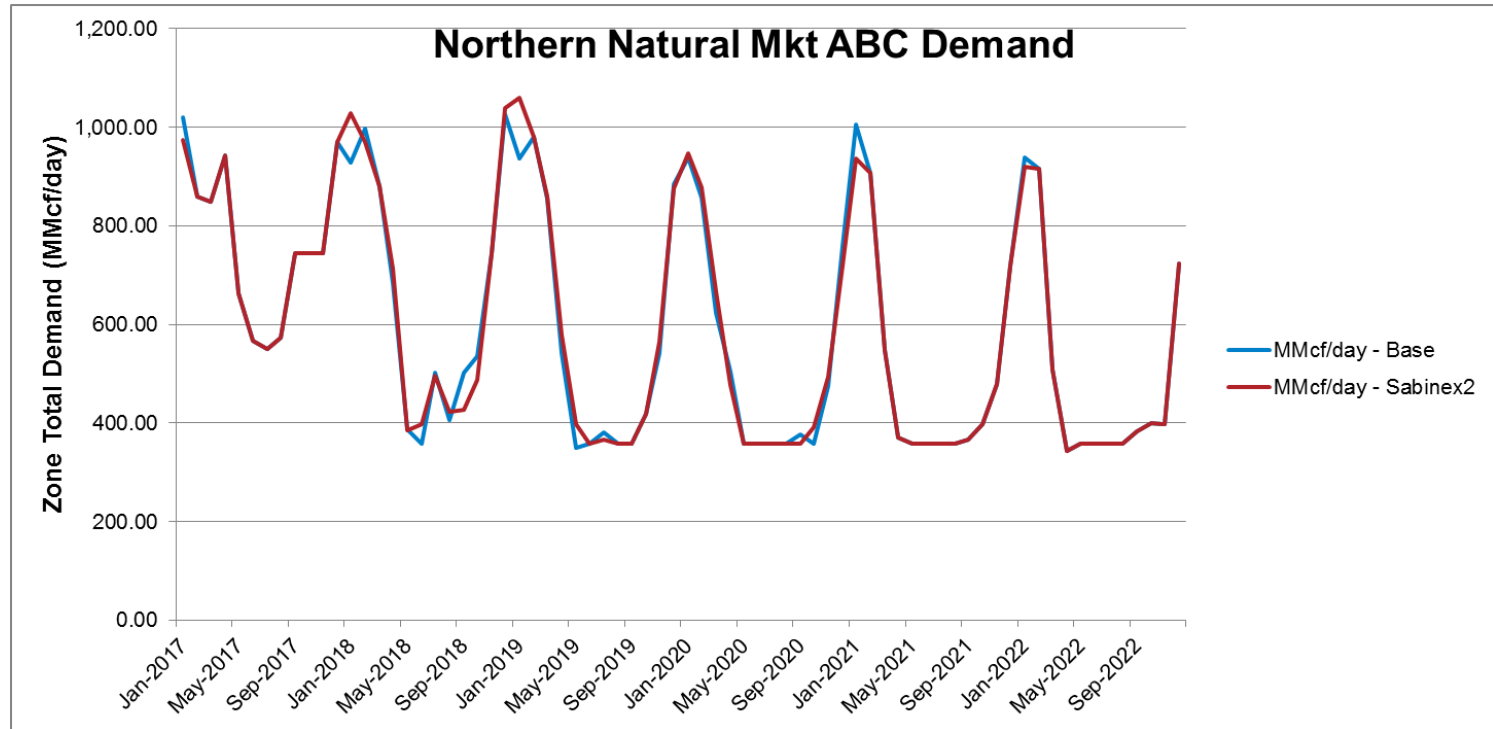
Actual demand does not follow the isogram levels, as gas prices are constantly fluctuating due to supply and demand trends from other customers and suppliers



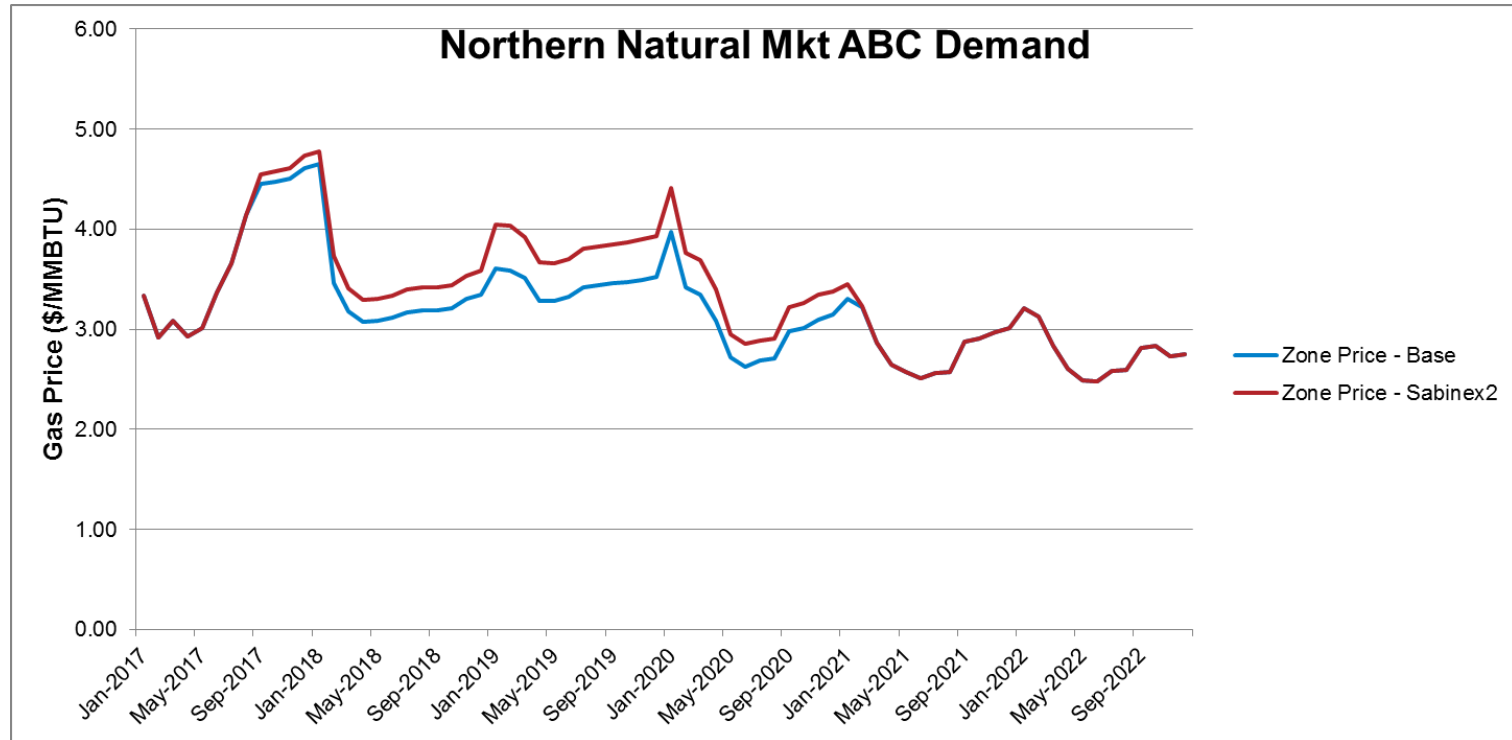
The Henry Hub price is strongly affected by an increase in LNG exports from Sabine Pass, given its proximity in the region. Prices increase by 40 cents in the summer of 2019



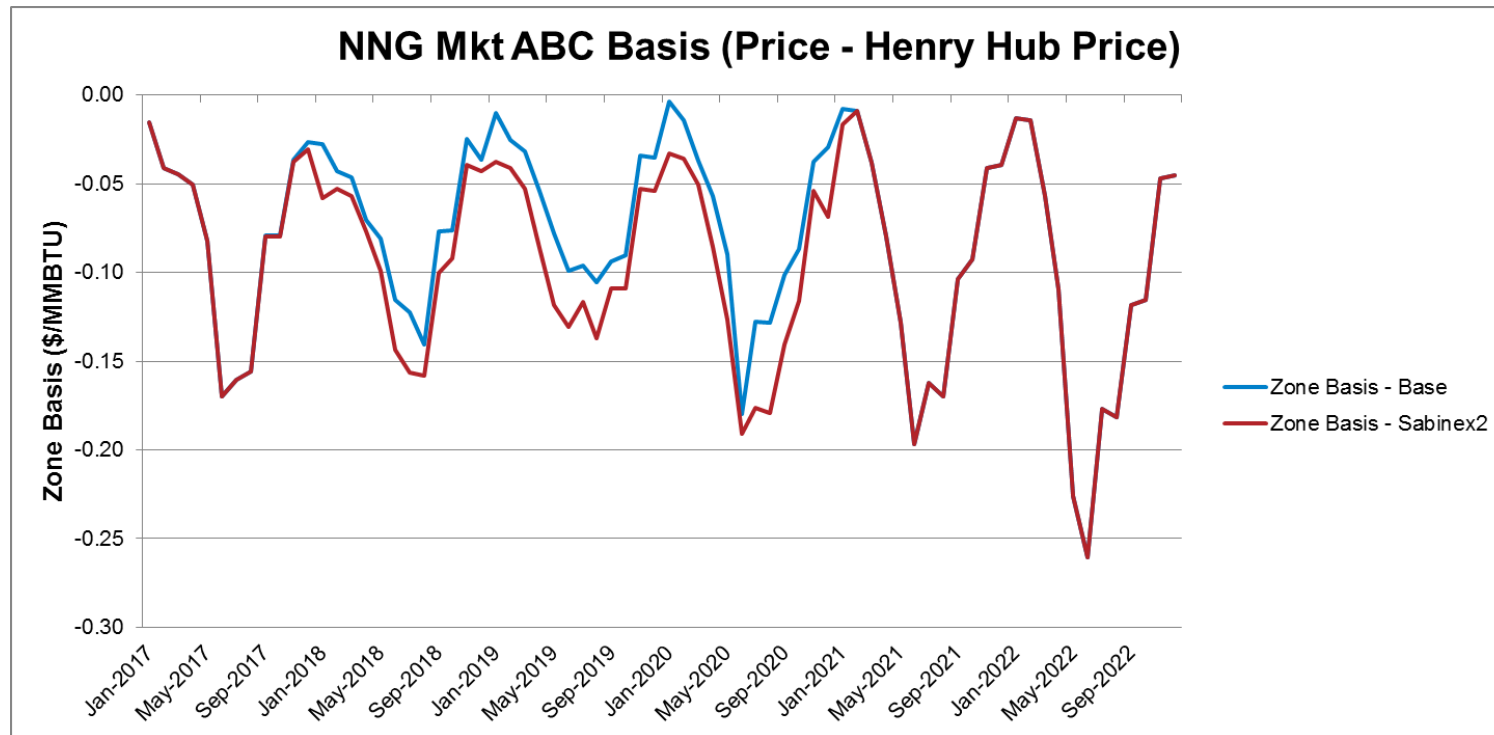
Even areas far removed from the Gulf South—like Northern Natural's Market ABC Zone in the Upper Midwest—are affected to some degree by a change in exports from the Gulf



While not affected to the magnitude that Henry Hub is, prices in the Upper Midwest still increase as a result of demand increases in the South



Increased demand from LNG Exports in the Gulf South lead to relatively higher prices in that region, including at Henry Hub. This means a lower basis for areas around the country



LNG exports affect consumption from generators across the country. A doubling of Sabine Pass exports could lead to a decrease in gas generation equivalent to approximately 4.4 GW

