Integrated Modeling of the North American Gas & Power Market

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Gas and Power Market Modeling Challenges

- **Revolutionary changes in the market**
  - Both gas and power markets are undergoing rapid change
  - Tremendous growth in natural gas production
  - Major restructuring of gas transmission systems
  - Increasingly severe regulation of emissions, including CO_2
  - Large increases in renewable energy and gas-fired generation with numerous coal and nuclear plant closures
- **Separate market models sufficient?**
  - Powerful highly-granular systems which model each market separately are available, but they do not include important aspects of the other market
  - Gas market models do not consider power transmission constraints, emissions regulations, government mandates and technological advances in renewables, etc.
  - Power market models do not consider gas pipeline constraints and expansions, storage, LNG imports and exports, etc.
- **What is the goal?**
  - A useful and realistic model of both gas and power markets

Research and Development Team

- **Dr. Robert Brooks, Founder, RBAC, Inc.**
  - Principal modeling system designer at RBAC
  - RBAC project lead for joint RBAC-EPIS projects

- **Dr. Rahul Dhal, Developer, EPIS, LLC.**
  - AURORAxmp scenario design, implementation, operation, and analysis
  - EPIS project lead for joint RBAC-EPIS projects

Fundamental requirements for useful tools

- **Realistic representation of market structure**
  - The US and Canada are competitive markets
  - Mexico is moving toward a more open market

- **High degree of infrastructure granularity**
  - Model the existing infrastructure, not abstract aggregations
  - Provide means for market-driven capacity additions

- **Detailed models of supply and demand**
  - Drivers must include economics, weather, price response, alternative fuels, government mandates regarding renewables and emissions reduction

Forecasting tools meeting these requirements

- **GPCM® Natural Gas Market Forecasting System**
  - RBAC, Inc., Los Angeles, CA, and Houston, TX
  - First released in 1997
  - Used by over 35 licensees in North America

- **AURORAxmp® Electric Power Model**
  - EPIS, LLC., Sandpoint, ID, Salt Lake City, UT, Portland, OR and Utica, NY
  - Also first released in 1997
  - Used by over 90 energy companies in North And Latin America, Europe, Asia and the Middle East

GPCM gas market model overview

- **Competitive market clearing model**
  - Non-linear multi-period partial equilibrium model
- **Monthly time frame**
  - Calibrated from Jan-2006 through Jun-2016
  - Forecasts from Jul-2016 through Dec-2040
- **Inputs include**
  - Price sensitive supply and demand functions
  - Detailed pipeline and storage infrastructure model
  - LNG imports and exports assumptions
- **Outputs include**
  - Basin-level natural gas and NGL production
  - State and sector level natural gas demand
  - Henry Hub and other market prices, basis and spreads
  - Detailed pipeline flow and storage activity
  - Pipeline capacity expansion requirements forecast

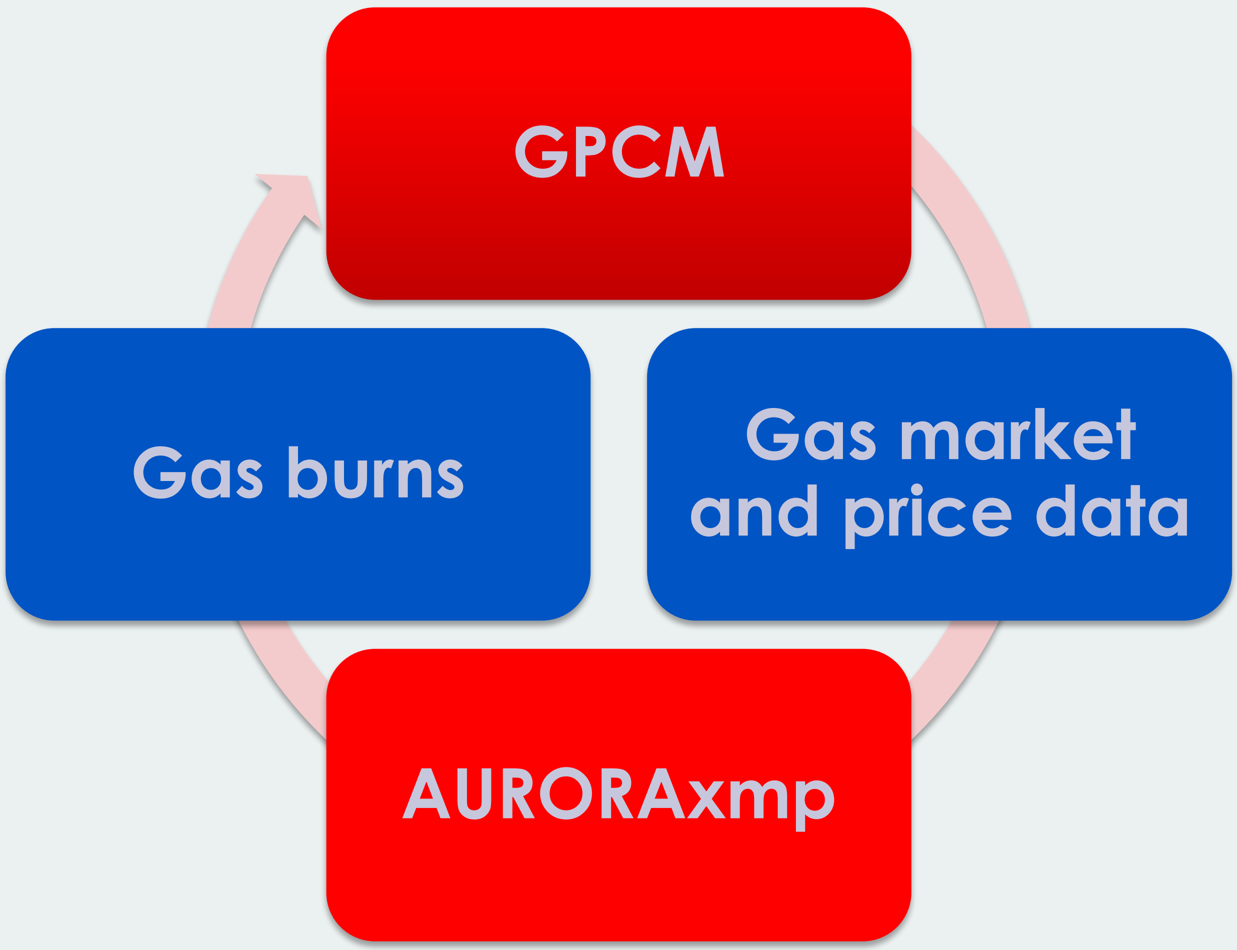
AURORAxmp power market model overview

- **Fundamentals-based dispatch model**
  - Databases for North America and Europe
- **Chronological solution**
  - Simulates unit commitment and dispatch at hourly or sub-hourly level
- **Time frames supported**
  - Day-ahead to 40 years out
- **Inputs include**
  - Existing, planned and additional required power plants and units
  - Fuel and emissions constraints, RPS and CPP
  - Transmission constraints: zonal or nodal-bus level
- **Outputs include**
  - Location-specific power market prices (zonal or nodal), generator dispatch, fuel burns & emissions, power flows, and capacity expansion requirements.

Can GPCM and AURORAxmp work together?

- GPCM needs a forecast of gas usage in power markets in order to compute gas prices which balance the market
- AURORAxmp needs a forecast of gas prices to compute the optimal fuel mix in power generation
- What happens if we set up an iterative loop between these two systems?
    - Will they produce a mutually consistent solution?
    - If so, how many iterations will be required for “convergence”?
    - How can we speed up the convergence?
    - How can we know when we’re “close enough”?

Combining GPCM and AURORAxmp



Mathematics of the iterative process

- Let **A** represent AURORAxmp and **G** represent GPCM
- Let **p** and **b** represent vectors of gas prices and gas burns
- Then
    - **A(p) = b** and **G(b) = p**
- Therefore
    - **A(G(b)) = AG(b) = b** and
    - **G(A(p)) = GA(p) = p**
- The problem is now defined as finding two fixed points, the vectors **b** and **p**, for the combined functions **AG** and **GA**
- In R & D conducted during March-April 2015, RBAC and EPIS designed and tested three different trial methods for finding these fixed points using *fixed point iteration*

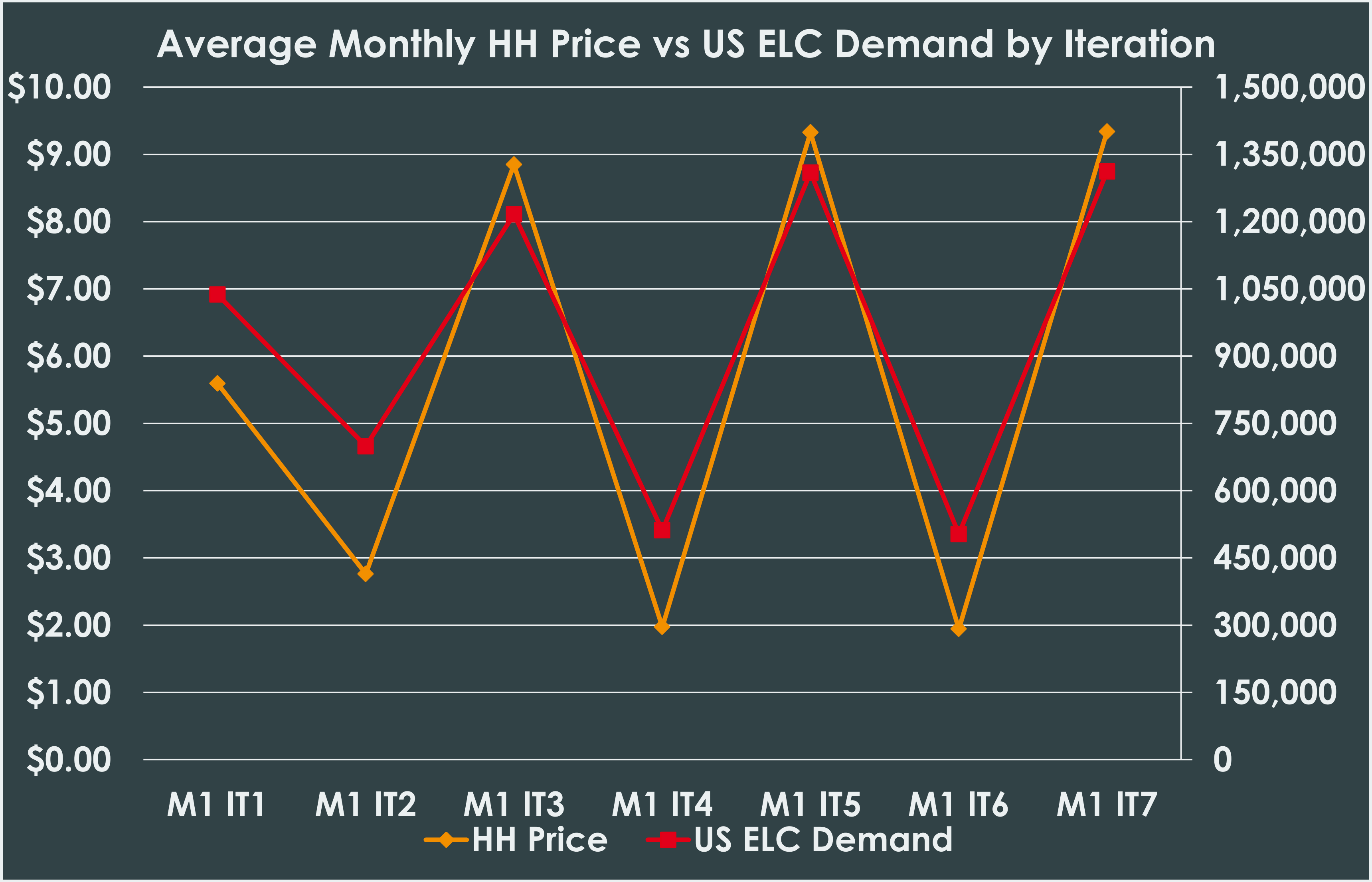
Iterative procedure: three trial methods

- **Method 1: Simple loop**
  - Send GPCM market prices as-is to AURORAxmp and send AURORAxmp gas-burns as-is to GPCM

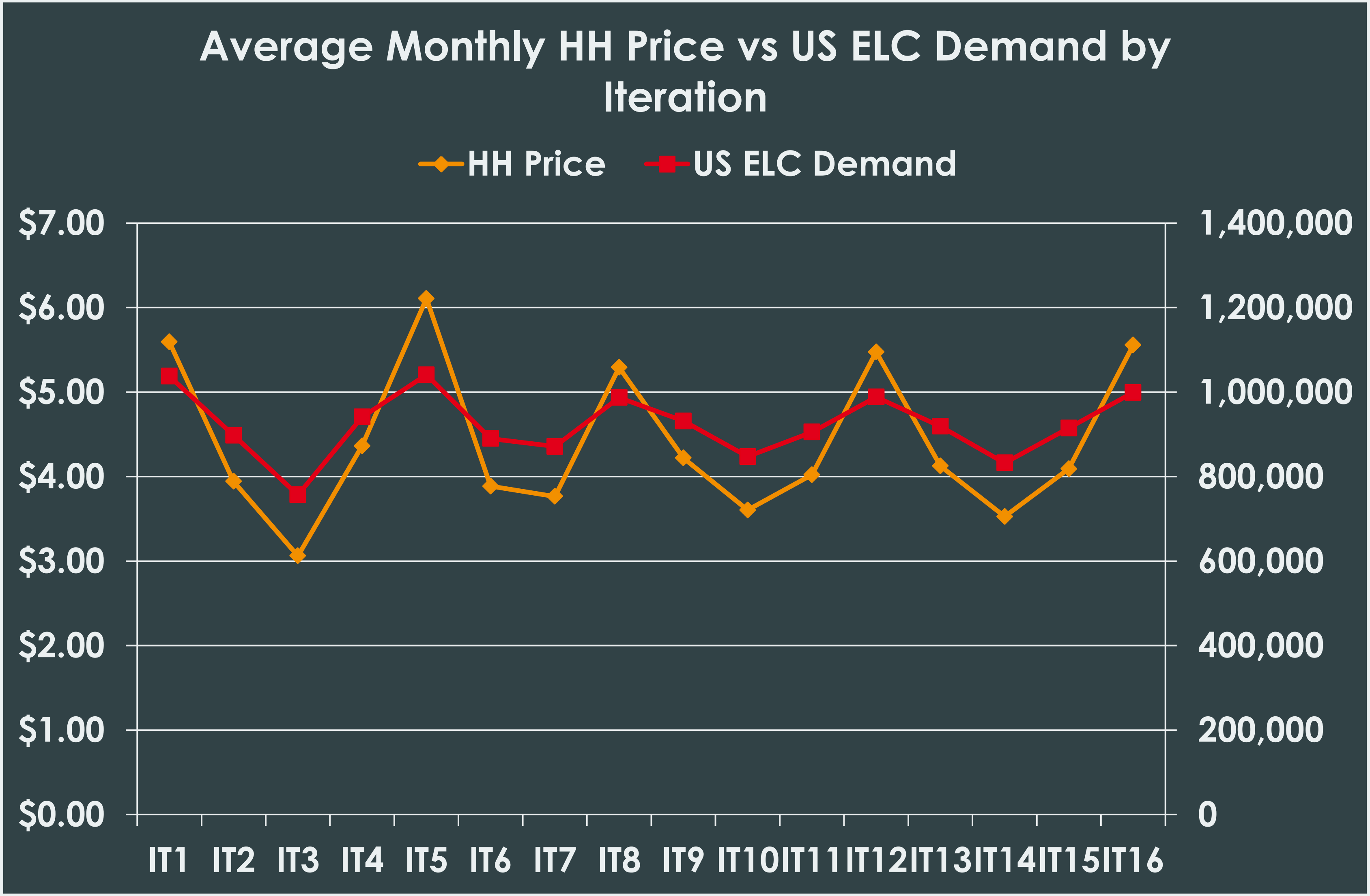
- **Method 2: Average of last two runs**
  - Send straight average of last two sets of market prices from GPCM to AURORAxmp and send straight average gas-burns from last two AURORAxmp runs to GPCM

- **Method 3: Exponential average of prior runs**
  - Send exponential average of **all** prior sets of market prices from GPCM to AURORAxmp and of **all** prior gas-burns from AURORAxmp to GPCM

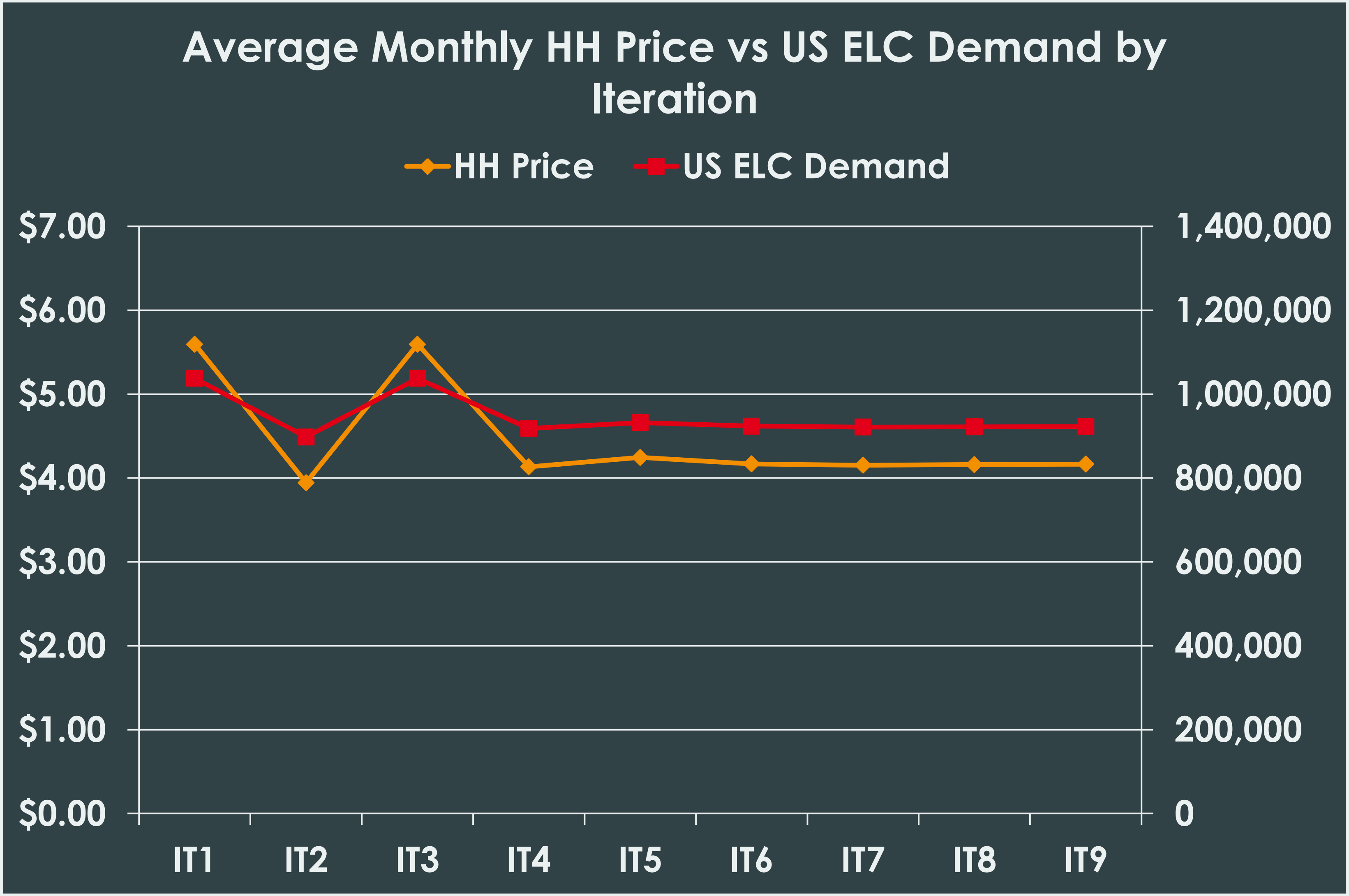
Method 1: HH Price & US Gas-Burn by Iteration



Method 2: HH Price & US Gas-Burn by Iteration



Method 3: HH Price & US Gas-Burn by Iteration



Conclusions of the algorithm development task

- Method 1 (simple iteration of prices and gas-burns) converged to a simple 2-iteration limit cycle rather than a single value for the vector of prices and gas-burns
- Method 2 (averaging two most recent sets of prices and gas-burns) converges to a more complex limit cycle of four iterations, but not to a single value
- Method 3 (exponential averaging) converges to an acceptable solution for both GPCM (prices) and AURORAxmp (gas-burns)
  - Exponential weights of 0.500 and of 0.618 (Golden Mean: φ) both worked, with φ producing a faster convergence
- See Appendix 1 for method 3 algorithm
- See Appendix 2 for proposed research topics

Application to a current issue: the CPP

- What is the CPP?
- What are its intended effects?
- How should it be modeled?
- What does the combined GPCM-AURORAxmp model predict for
    - Effect on power and gas prices?
    - Effect on future generation mix and fuel use?
    - Effect on requirements for new power generation and gas pipeline capacity?

The Clean Power Plan

- Clean Power Plan is a proposed legislation from Environmental Protection Agency aimed at ***limiting carbon pollution from power generation***
- States have various options to meet the reduction goal
  - A ***rate-based*** state goal measured in lb/MWh;
  - A ***mass-based*** state goal measured in total tons of CO_2;
  - A ***mass-based*** state goal with a new source complement measured in total short tons of CO_2.
- States are allowed to group together and/or form emission trading markets

Note:

- The Supreme Court has stayed the legislation while the judiciary deliberates on CPP’s merits and legality.
- Some form emission reduction legislation is expected to be in effect in near future

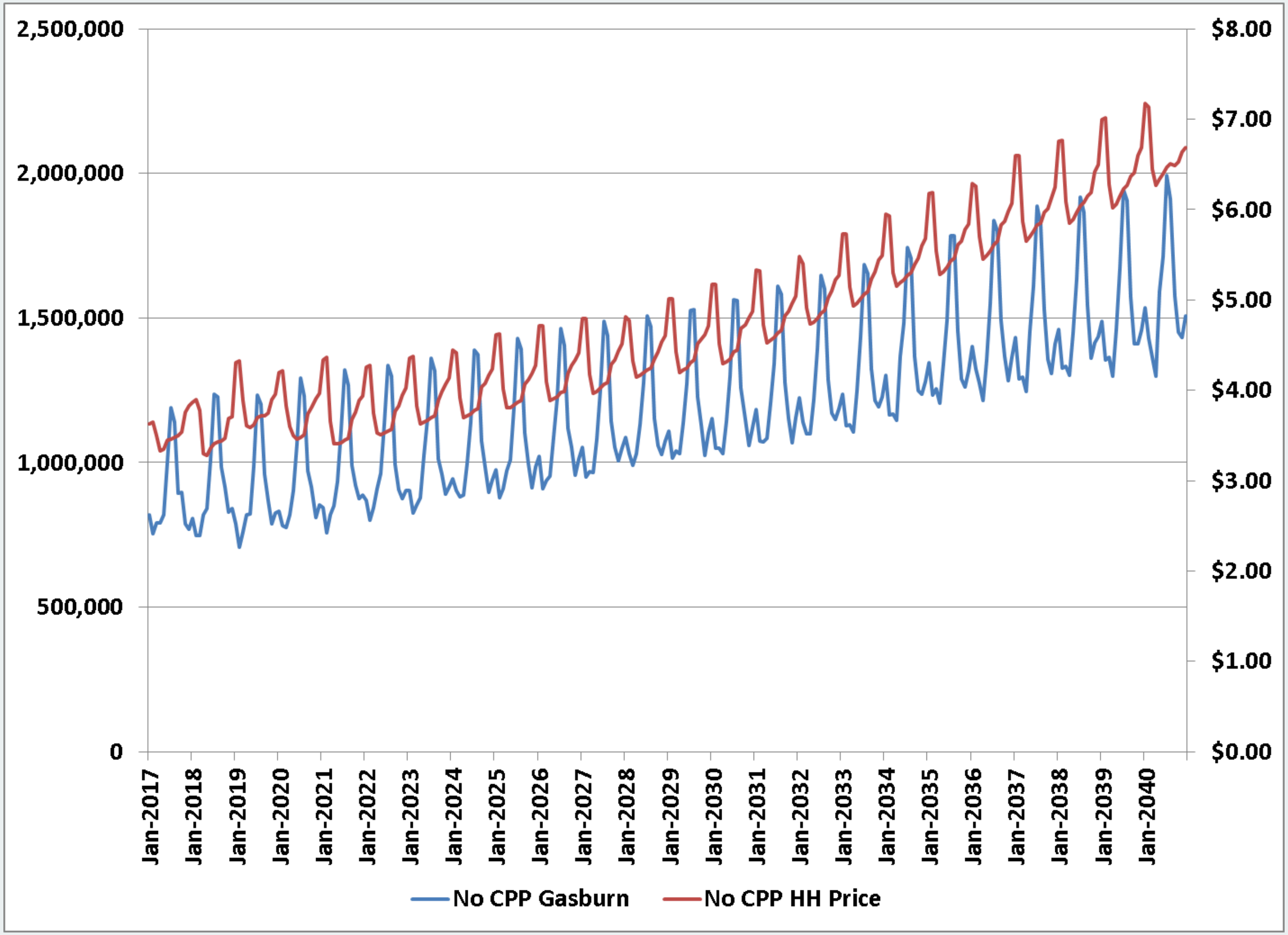
Intended Effects of CPP

- EPA's expectation for CPP (when in effect) is that it will ***accelerate the transition clean energy***
  - ***Fossil fuels*** will continue to be ***critical in near future***
  - Emphasis is on ***making fossil fuels efficient***, while
  - Fostering ***expansion of zero- and low-emitting power sources***
- CPP objectives also need to consider **reliability issues**.
- ***Reliability of power generation is somewhat incongruous with CPP objective***
  - Cheapest way to ensure reliability is through fossil-fuels
  - Renewables are intermittent; storage technology is still embryonic; nuclear is expensive and lacks general support
  - State need to demonstrate reliability issues have been considered in the emission reduction plan.

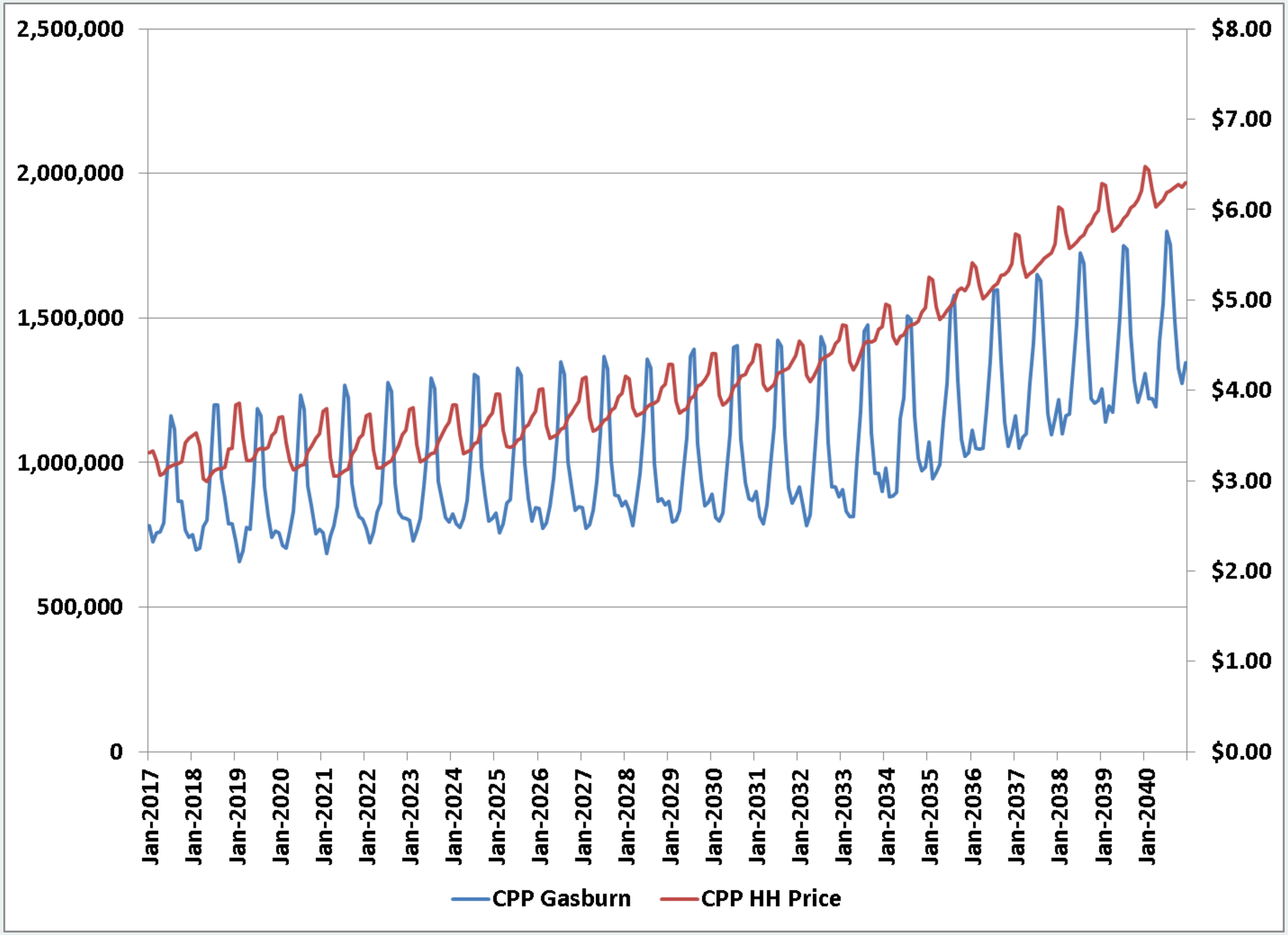
Two Scenarios: No CPP and CPP

- No CPP
  - Assumes CPP is not implemented but …
  - State level RPS plans are enforced
- CPP
  - Assumes CPP is implemented as follows:
    1. Mass-Based New Source Complement target
       - Targets were derived based on EPA’s estimates
    2. Carbon target become binding in 2022
       - Targets are progressively more binding till 2030, after which they remain constant
    3. States independently meet their targets
  - And state level RPS plans are also enforced
- Forecast Horizon: Jan-2017 to Dec-2040 (monthly)

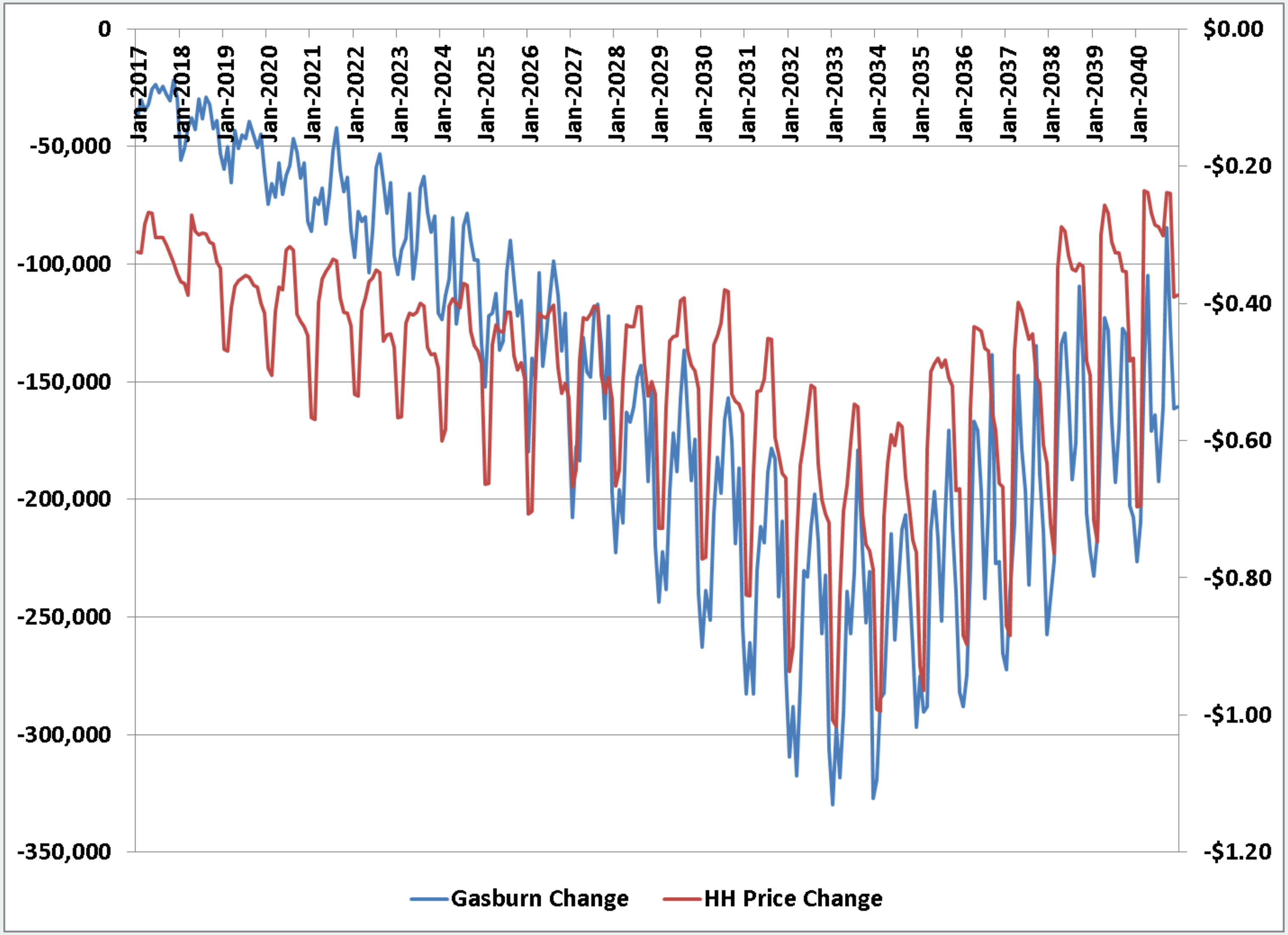
No CPP Case: Gasburn vs Henry Hub Price



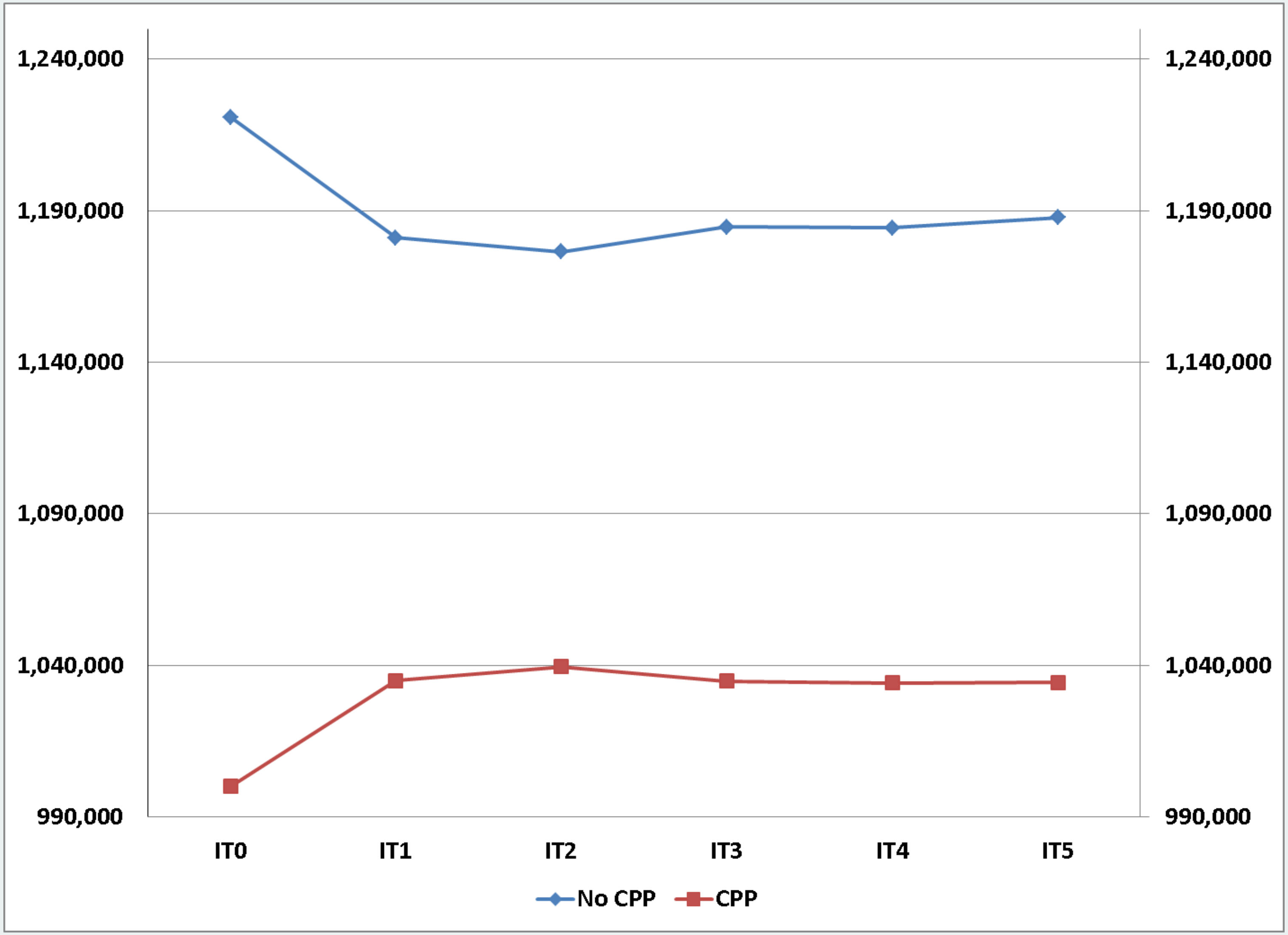
CPP Case: Gasburn vs Henry Hub Price



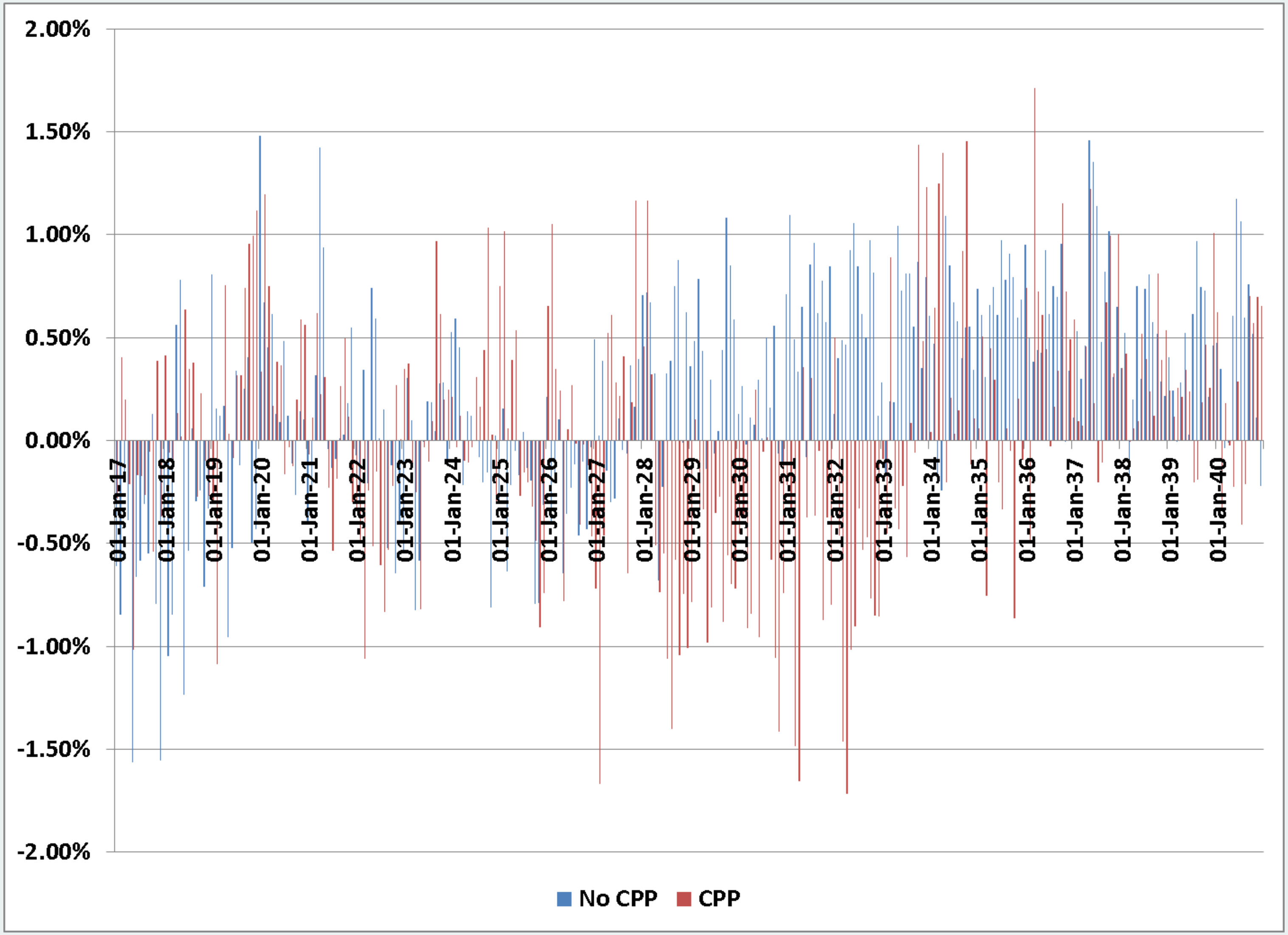
Gasburn Change vs Henry Hub Price Change



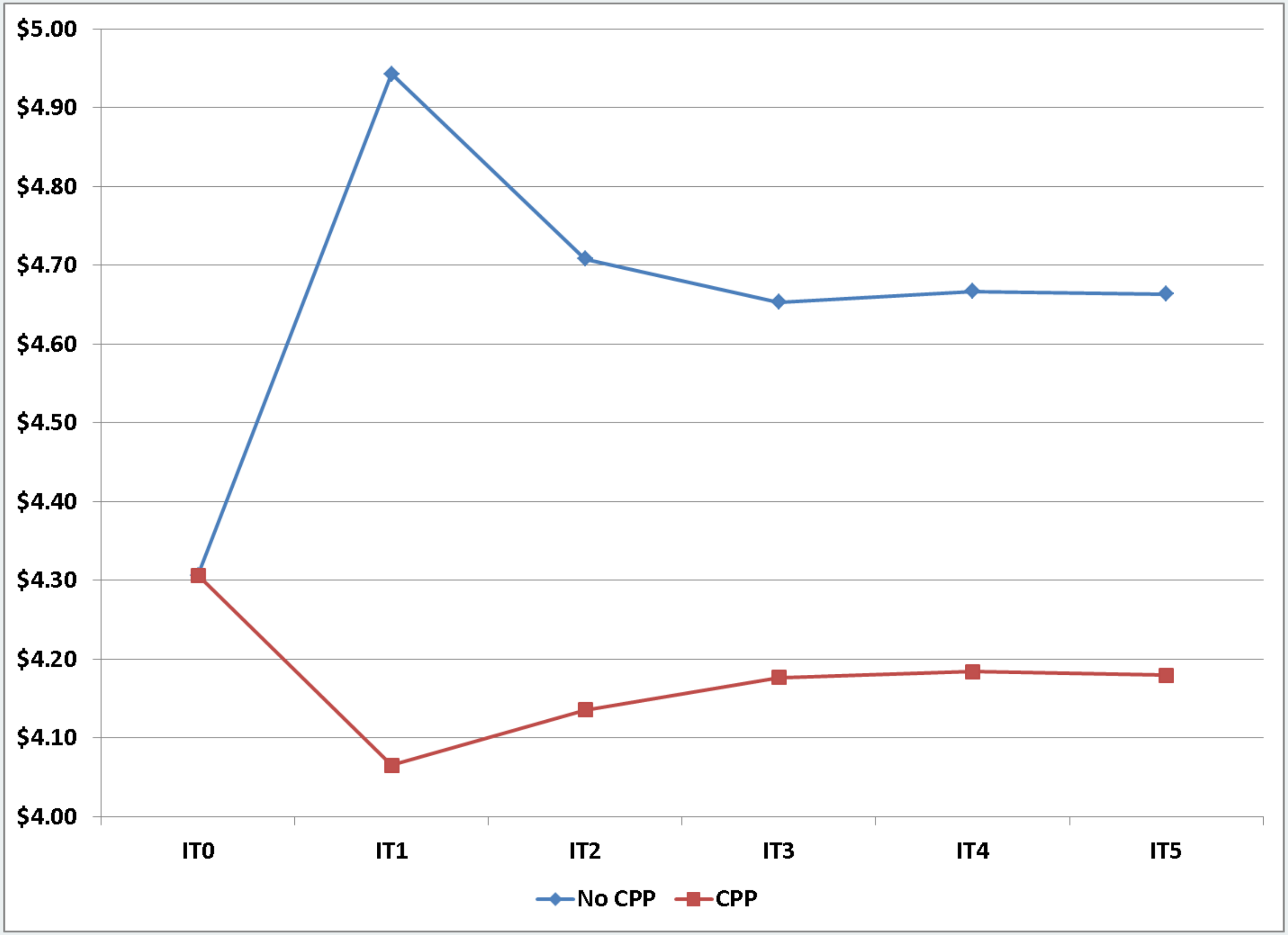
Average Monthly Gas-Burn by Iteration



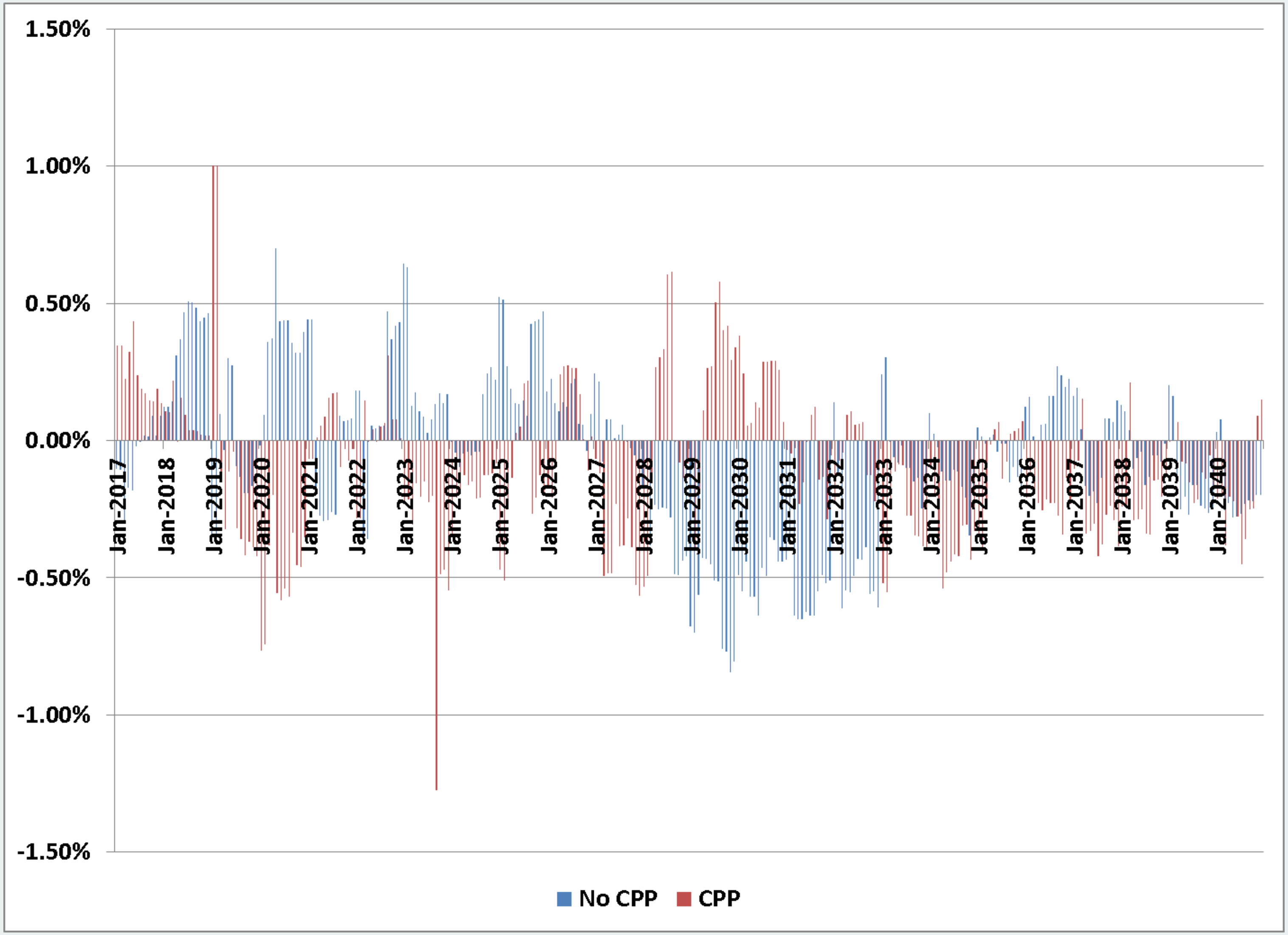
Total Gasburn Change: IT5 vs IT4



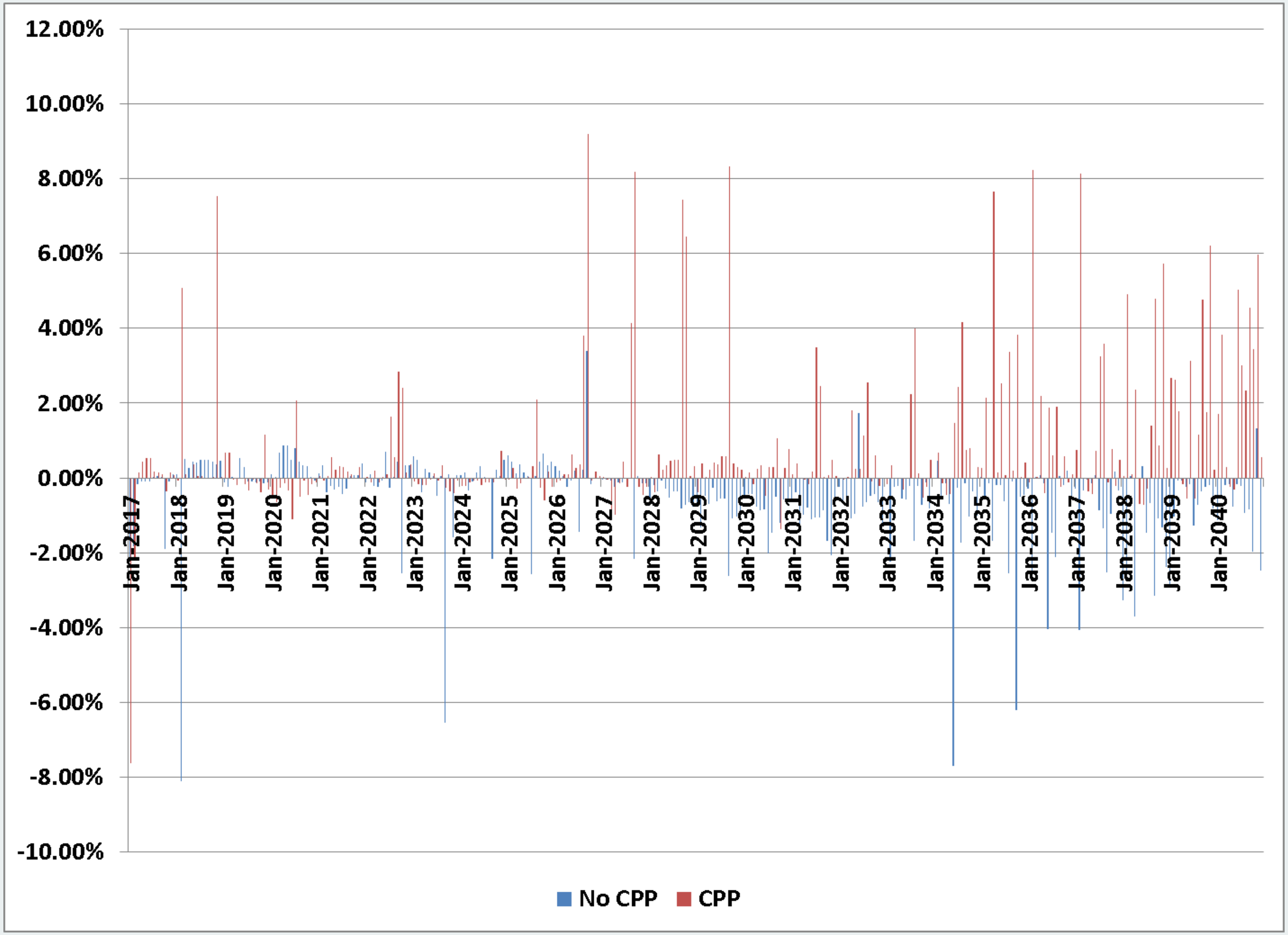
Average Henry Hub Price by Iteration



Henry Hub Price Change: IT5 vs IT4



Dracut (No MA) Price Change: IT5 vs IT4



Conclusions

- The Clean Power Plan reduces demand for natural gas
  - Renewables growth reduces coal and gas generation
- This reduction lowers prices and frees up gas for other use
  - Industrial demand
  - Pipeline exports to Mexico
  - LNG Exports to Latin America, Asia, Europe
- The combined gas-power market model methodology works
  - Reasonable convergence (1-2%) in most markets achieved within five iterations for both models
- Local exceptions can occur
  - Dracut price point still oscillating after 5 iterations
    - Fuel switching between natural gas and fuel oil might be causing this trouble

Appendix 1: Method 3 Algorithm

- Let **A** represent AURORAxmp, **G** represent GPCM, and **p** and **b** represent vectors of gas prices and gas burns, respectively
- Define two new vectors, $\boldsymbol{\pi}$ and $\boldsymbol{\beta}$, as follows, where $\boldsymbol{\varphi}$ is a parameter on the interval (0,1], and n = 0, 1, 2, …:
    - $\beta_{n+1} = \varphi * b_n + (1 - \varphi) * \beta_n$
    - $\pi_{n+1} = \varphi * p_{n+1} + (1 - \varphi) * \pi_n$
- Given $\pi_0 =$ initial price vector from GPCM, not necessarily based on AURORAxmp gas-burn, and n = 0:
- While process has not yet converged
    - Compute gas-burns: $b_n = A(\pi_n)$
    - Compute weighted gas-burn: $\beta_n = \varphi * b_{n-1} + (1 - \varphi) * \beta_{n-1}$
        - if n=0 set $\beta_0 = b_0$
    - Compute prices: $p_{n+1} = G(\beta_n)$
    - Compute weighted prices: $\pi_{n+1} = \varphi * p_{n+1} + (1 - \varphi) * \pi_n$
    - Iterate (n = n + 1)
- Note: convergence or cycling criterion is defined using differences in prices or gas-burns between consecutive or every other iteration

Appendix 2: Proposed research topics

- Experimental program using different values of the exponential weighting factor
- More rigorous mathematical analysis of the convergence requirements and properties of various fixed point iteration schemes
- Experimental program using an adaptive algorithm where the value of the weighting function for the next iteration depends on the results of prior iterations.
    - Can an algorithm be defined which speeds convergence with such an approach?
    - What are the mathematics behind it?

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