DOE Bioenergy Technologies Office (BETO) 2017 Project Peer Review

Biofuels National Strategic Benefits Analysis

March 7, 2017

Strategic Analysis and Sustainability

Principal Investigator: Paul Leiby (ORNL)

Co-Investigators:
Rocio Uria-Martinez (ORNL) and
Maxwell Brown (Colorado School of Mines)

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Goal Statement

- To assess, quantify and communicate potential fuel market impacts and overall economic and security benefits associated with biofuels
  - Focus on interactions between petroleum-based and biofuel-based U.S. fuel supply chains
    - Q: What is the effect of biofuels on oil use, fuel price level, fuel price volatility and ability to mitigate costs of oil price shocks?
    - A: It depends… on oil price regime, RFS implementations, foresight levels and supply chain configurations

Relevance and tangible outcomes for the U.S.:

- Evaluation of benefits, costs, and resilience of alternative biofuel supply chain configurations
- Provide insight on strategies to effectively achieve an *economically sustainable* advanced biofuel industry
- Understand role and implications of biofuels in changing oil markets
  - Do biofuels still provide energy security benefits in a time of low petroleum prices and decreasing petroleum import share?

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Quad Chart Overview

Timeline

- BETO funding started in 2012 building on an ORNL LDRD project
- 2017 Peer Review project cycle:
  - Start date: 10/01/2015
  - End date: 09/30/2017
  - Percent complete: ~80%

Barriers

- Barriers addressed (from MYPP, March 2016)
  - St-A: Scientific Consensus on Bioenergy Sustainability
    - Explaining and quantifying energy security benefits of biofuels
  - At-B: Analytical Tools and Capabilities for System-Level Analysis
    - BioTrans model

Budget

	FY 15 Costs	FY 16 Costs	FY17 Costs
DOE Funded	$350K	$250K	$300K
Project Cost Share (Comp.)*	0	0	0

Partners

- Partners
  - Maxwell Brown (CO School of Mines)
  - NREL/ANL for past high-octane fuel market assessment task
  - EPA for work on energy security premium
  - DOE-EPSA
- Other interactions/collaborations
  - NREL (for model scenario comparisons, data sharing and benchmarking)

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1 - Project Overview

- Context:
  - Oil price volatility, regulatory uncertainty (RFS-2), blend wall, declining oil import dependence
  - How are biofuel industry growth prospects and energy security objectives affected by these market trends and uncertainties?
- History:
  - Past analyses for DOE exploring alternative fuel transitions (e.g., hydrogen)
  - Prior oil security premium work for DOE and EPA relevant for biofuels
  - Interdisciplinary ORNL team builds off internal project, and existing BETO models/data
    - Add representation of biorefinery-to-pump, depict petroleum fuel-biofuel blend interactions
    - Evaluate policies and engineering/operational strategies to enhance resilience of the combined fuel supply chain

2 – Approach (Management)

- Internal coordination:
  - The 3 project investigators collaborate closely
    - Analytical tool development and design of scenarios to address research questions
    - Workflow automation, version control and code testing to facilitate collaboration
  - Frequent communication with other ORNL teams working on related projects
- External coordination:
  - Data and soft linkages with related models/projects
    - POLYSYS (biomass feedstock supply)
    - NEMS (petroleum market reference conditions),
    - ADOPT and MA3T (vehicle choice modeling)
    - TRIM (petroleum transportation and refinery infrastructure model)
  - Model comparison/validation
    - Close collaboration with NREL's BSM team in renewable super premium market assessment involved running set of coordinated scenarios and delving into differences between BSM and BioTrans modeling approaches
  - Participation in BETO monthly A&S calls, Bioenergy Modeling Workshops, BSM review workshop
  - Engagement with DOE/EPSA on quantification of economic impact of oil price shocks and other energy security-related work.

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2 – Approach (Technical)

Challenge: Assessing fuel market impacts & energy security role of biofuels

- Research questions are decided with input from BETO, Peer Review, and insights from closely following energy economics and energy security literature
- Methods:
  - Long-run optimization model of biofuel supply chain(BioTrans)
    - annual periods (2010-2040), national scope with regional disaggregation
    - dynamics of investment decision and consumer and producer responsiveness to market shocks
    - model solutions underpinned by material balances and *economic equilibrium conditions*
  - Empirical analysis of historical market data
    - Time-series econometric techniques to estimate effect of biofuels on retail fuel price levels and volatility
    - Calculation of energy security premium of biofuels (per barrel of oil displaced)
      - Based on probabilistic assessment of oil supply risk and analysis of the marginal effects on U.S. welfare of decreasing oil imports
- Challenge: Validation of approach and results
  - Model comparison exercises (e.g.; BioTrans - BSM joint scenario analysis)
  - Peer-review
  - Seek to use empirical analysis or meta-analysis to benchmark some BioTrans input parameters

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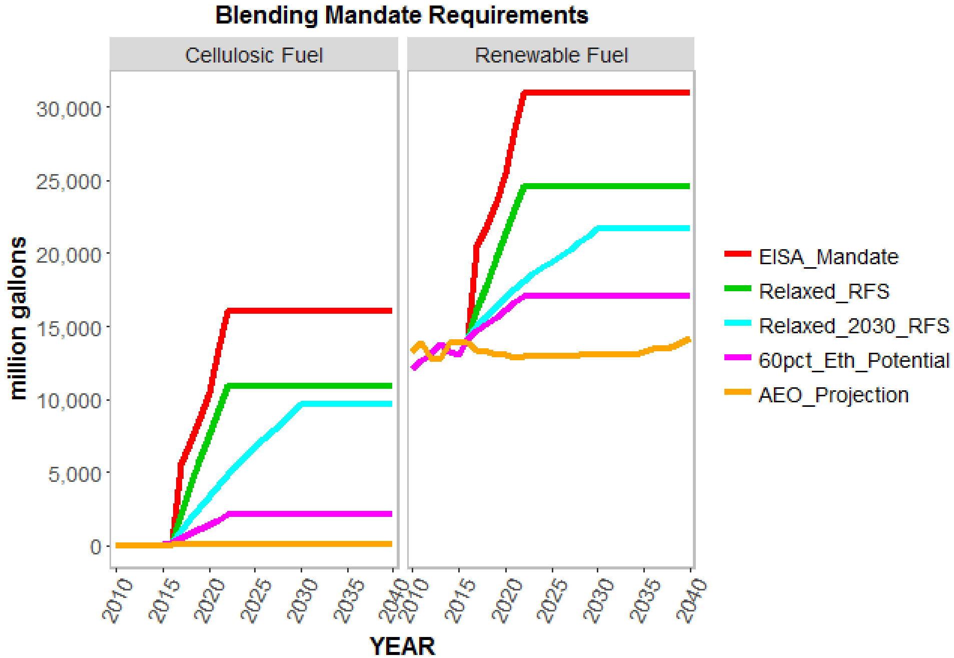
3 – Technical Accomplishments/ Progress/Results

Selected FY15-FY17 deliverables	Accomplishments/Results
3.1. Analysis of biofuel production, RIN prices, fuel mix, prices & benefits under alternative biofuel blending mandate futures (FY15 Q3)	• Comparison between physical and economic ethanol use limits for various oil price levels and foresight representations.
3.2. Report on energy security role for biofuels under various combinations of oil market futures and oil supply shocks based on BioTrans simulations (FY15Q4)	• The biofuel portion of the U.S. LDV fuel supply chain mitigates fuel price changes at the pump in the event of oil price booms or busts. • Biofuel blending mandates and petroleum import levels are important variables in determining oil supply shock costs.
3.3. Technical note on new empirical analysis quantifying the energy security premium of biofuels (FY16Q2)	• Updated premium estimates show declining monopsony portion of premium, while quantifying remaining benefits from reducing expected macroeconomic shock costs.
3.4. Report on estimation of gasoline and ethanol price volatilities and exploration of portfolio benefits and price stability effects from diversification with blended fuels (FY16Q4)	• Completed M-GARCH estimates measuring volatility dynamics and indicating modest reductions in fuel price volatility through fuel blending

3.1-Modeling alternative RFS futures provides insights on attainable levels of ethanol use



- Finding: Both *EISA_mandate* and *Relaxed_RFS* targets may be too ambitious without drop-in biofuels or big oil market shifts
- Finding: Renewable RIN prices often well above $1
- Insight: useful to recognize both *Physical Blend Wall* and "*Economic" Blend Wall* (28.5 vs. 21-24 bill gall in 2022)
- Insight: Attainable biofuel use depends on oil market outcomes, RFS mandate, *and* predictability of future outcomes (foresight accuracy)

Constraints:	Biorefinery capacity intro rate	Biofuel blending mandate	RIN banking constraints	Alternative retail infrastructure intro rate	*Economic* Blend Limit
Note: Limited Foresight, Reference Oil Prices, Ethanol-based Biofuels only					
EISA Mandate	>-10years (red)	>-10years (red)	4-9 years (blue)	4-9 years (blue)	>-10years (red)
Relaxed RFS	1-3 years (yellow)	>-10years (red)	4-9 years (blue)	4-9 years (blue)	>-10years (red)
Relaxed_2030_RFS	0 years	>-10years (red)	>-10years (red)	1-3 years (yellow)	0 years
60pct_Eth_Potential	0 years	>-10years (red)	4-9 years (blue)	0 years	0 years
AEO_Projection	0 years	>-10years (red)	1-3 years (yellow)	0 years	0 years

Legend: Number of years in which constraint is binding
0 years (white) 1-3 years (yellow) 4-9 years (blue) >-10years (red)

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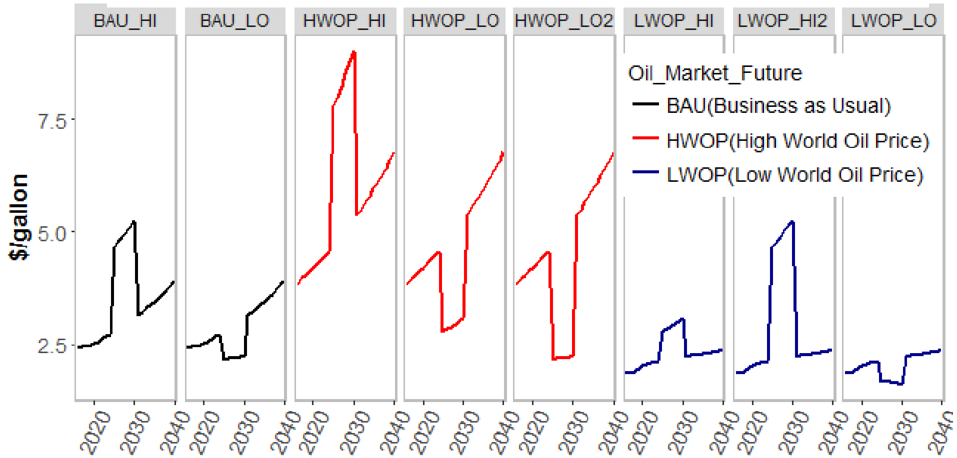
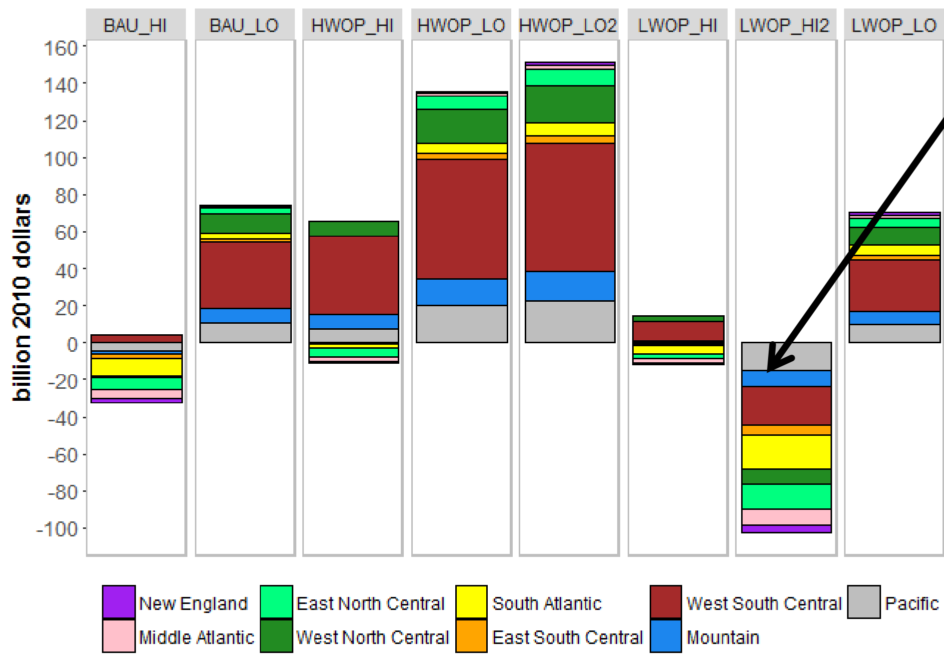
3.2- Study modeled a range oil supply shocks (under various conditions). Estimated shock costs from BioTrans offer one energy security metric.

Simulated Wholesale Gasoline Price Trajectories (Input)



Change in Net Private Welfare due to Oil Supply Shocks
(by Census Division)



- Method: Simulate combinations of 3 oil market futures and 2025-2030 oil supply shocks, up and down
- Finding: The largest shock cost is for a sharp price increase from a low oil price regime (which has less biofuel)
  - ($102 billion) corresponds to the LWOP_HI2 shock which changes the sign of $P_{gaso} - P_{eth}$ from >0 to <0
- Explore regional distribution of costs or benefits:
  - All HI shocks are harmful for regions *not* producing petroleum (e.g., South Atlantic)
  - Potential price-spike mitigation benefits of biofuels especially valuable for these regions

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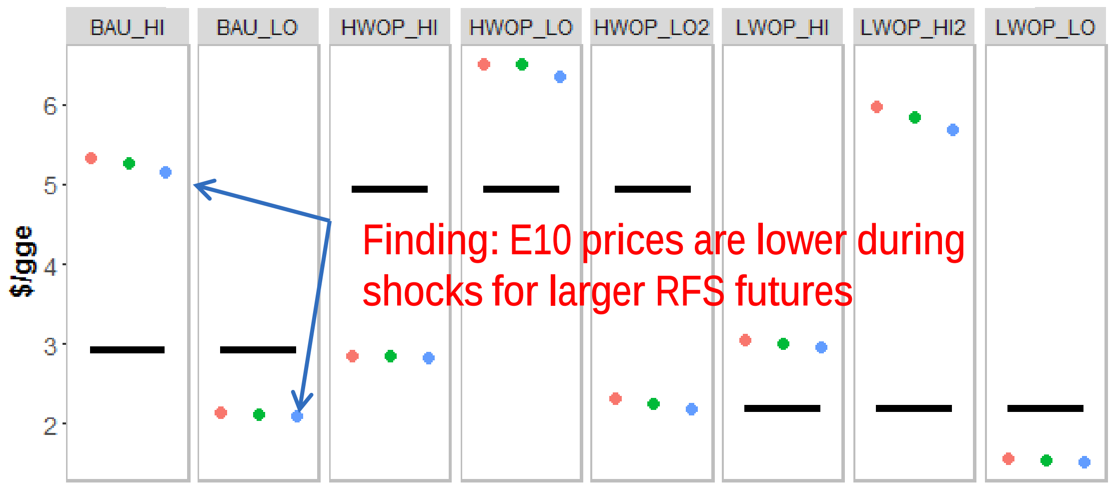
3.2- Then examined potential benefits of biofuels during shocks. As a substitute for gasoline, ethanol mitigates retail fuel price changes & costs during oil supply shocks

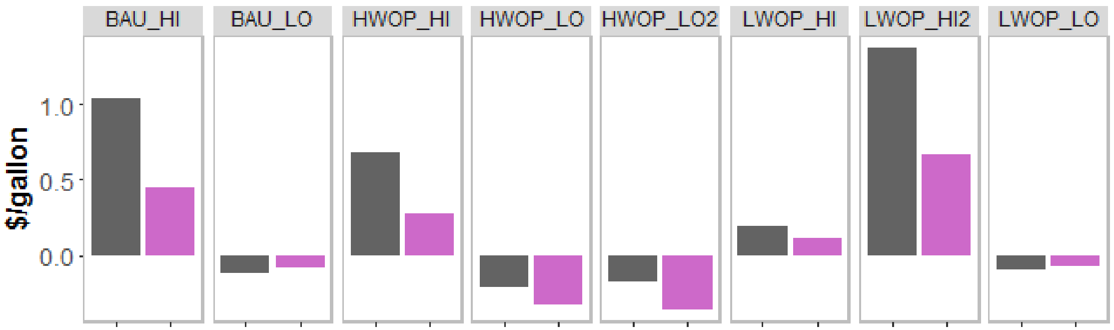
Average E10 Prices during Shock Period (2025-2030)



Note: black lines correspond to average prices in the absence of shocks

AEO_Projection • 60pct_Eth_potential • Relaxed_2030_RFS

Change in Net Private Welfare per Gallon of Additional Biofuel Use (2010$/gallon)



60pct_Eth_Potential vs. AEO_Projection
Relaxed_2030_RFS vs. 60pct_Eth_Potential

- Method: simulate the same shocks under various blending mandate levels, and biofuel configurations
- Key Feature: BioTrans accounts for detailed short-run responses & constraints along fuel supply chains
  - e.g. fuel prices, production capacity utilization, low-blend substitution and FFV fuel switching
- Finding: For any given shock, the equilibrium price of retail fuels is lowest for the case with the more aggressive blending mandate
- Find tradeoffs: Increased ethanol use mitigates cost of gasoline price increases but limits benefits from price decreases

3.3- Another security benefits metric updates and applies estimates of "Oil Security Premium" to amount of oil displaced by biofuel

<u>Method</u>: Oil security premium ($/barrel) reflects marginal economic costs associated with security and market power not accounted by private agents

- Methodology conforms to that used by EPA in RIAs and in other DOE work

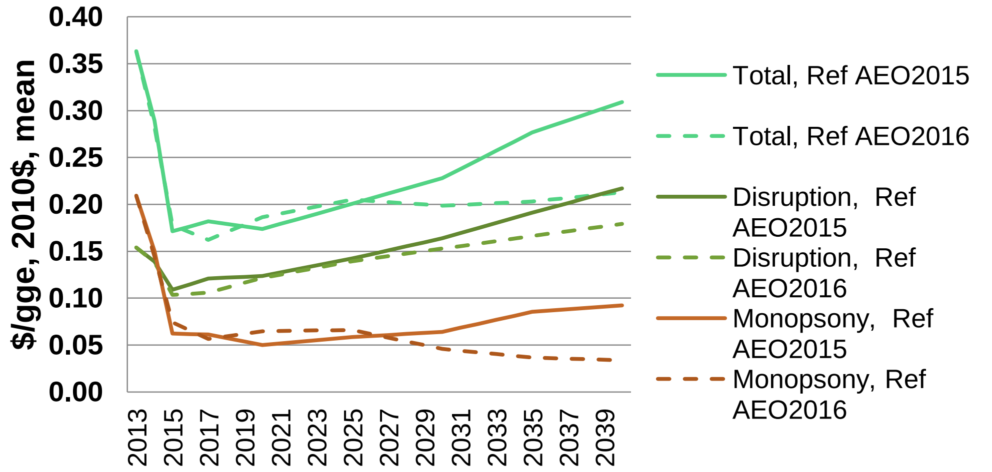
<u>Finding</u>: Premium ($/bbl oil use) has decreased significantly under recent market conditions

- Monopsony (demand) effect becomes very small over time, as imports diminish
- Expected macroeconomic disruption costs may increase modestly over time, but less

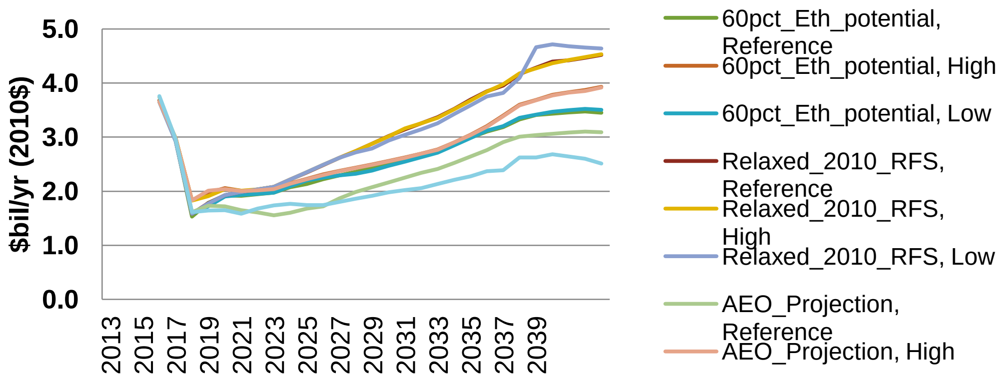
Key determinants:

- Degree of non-competitive mkt behavior
- Likelihood of oil shocks
- Price effect of oil supply shocks
- Economic costs of oil price spikes

Energy Security Premium ($/gge)



Estimated Energy Security Benefits from Biofuel ($bill/yr, 2010$)



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3.4- Examine implications of Biofuels for Price Volatility, Energy Security

- Biofuels can affect price *levels*, but fuel price *volatility* also matters
  - Important for economic stability (viability of biofuels industry), energy security
  - Influential on economic costs (e.g. Ferderer 1996, Auerbach & Sauter 2006, Elder & Serletis 2010, and Jo 2011)
- Investigating implications of biofuels for fuel price volatility
  - Q: Are there “portfolio diversification” benefits from biofuels, (reducing overall volatility)?
- Approach: Empirical M-GARCH models of volatility (variance) and “volatility clustering” for ethanol and gasoline

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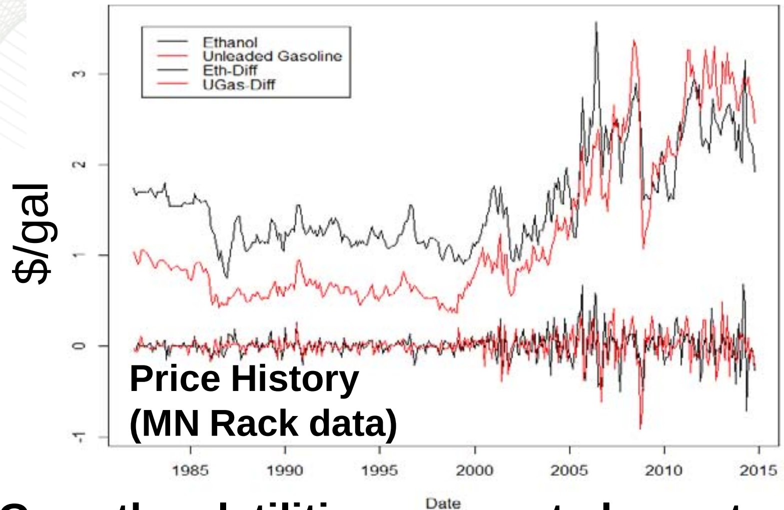
3.4- Ethanol-gasoline price volatility analysis indicates some portfolio benefit from ethanol blending

Rack Fuel Prices and Their Changes

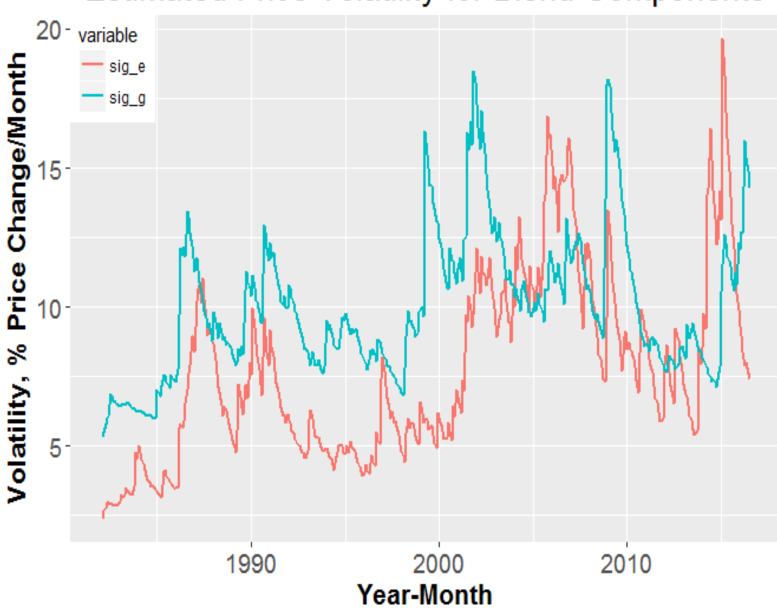


Progress:

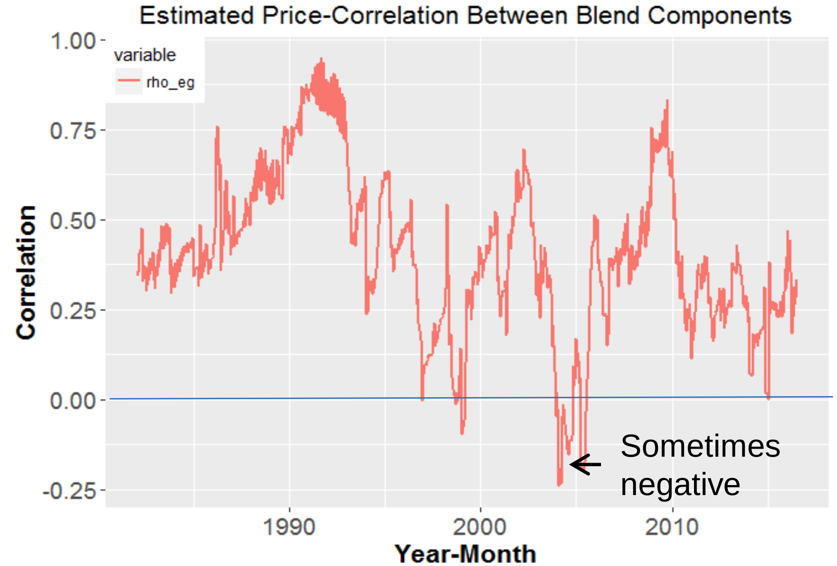
- Completed multivariate-GARCH volatility models
  - (jointly, for both fuels) showed
- Estimated time paths of price volatilities
  - for Eth and Gaso, and *correlation* of price changes
- Estimated "portfolio diversification benefits"
  - in terms of reduced volatility, from blending fuels

Gas-eth volatilities vary, not always together

Estimated Price Volatility for Blend Components



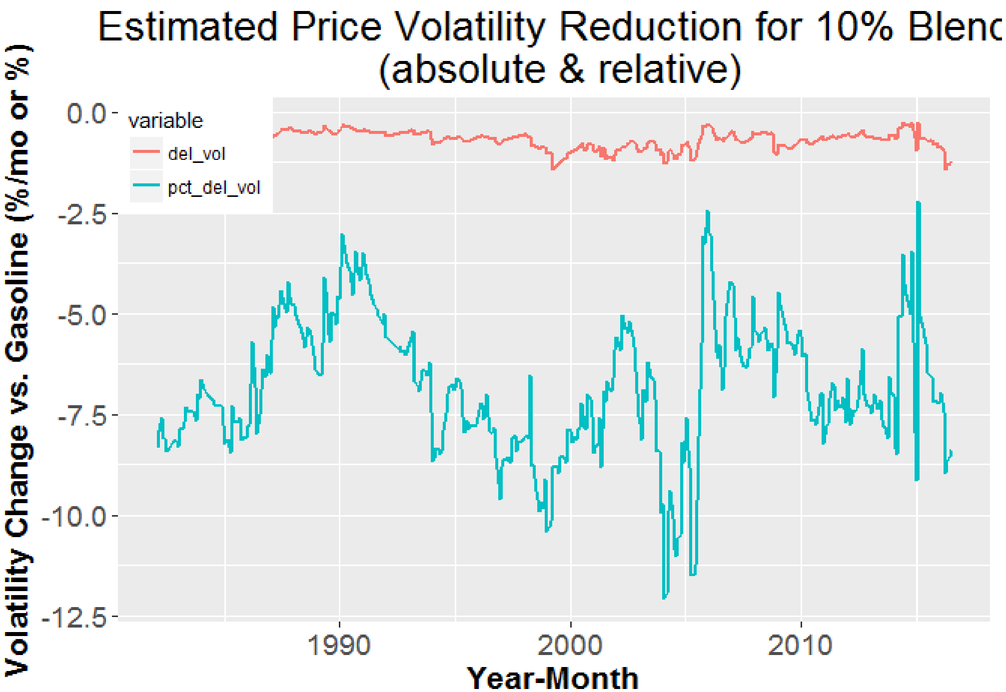
Gas-eth correlation is neither constant nor steadily increasing



3.4- Estimated 3-10% Potential Volatility Reduction Benefits from E10 Blend

Based on Historical Data 2006-16. Possible greater reductions from higher blends.

- Can provide range of volatility benefits (%) for alternate blend levels
- Estimating economic benefit ($/gal) necessarily uncertain
- Connections to biofuel modeling like BioTrans: benchmark market interactions, inform another aspect of benefits



Blend Level (assumed fixed)	Average Reduction in Fuel Price Volatility	Estimate of Economic Benefits ($/gal)
0%	0	0
Actual, 2006-2016	4.5%	? (TBD)
10% , 2017-2027	6.3% (~4-8%)	? (TBD)
15% , 2017-2027	8.9%	? (TBD)
20% , 2017-2027	11.3%	? (TBD)
25% , 2017-2027	13.3	? (TBD)

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The various tools/analyses used in this project vary in their focus but are all interrelated and can inform each other

- One way to evaluate RIN prices obtained from BioTrans is by comparing them to energy security premium of biofuels, plus other environmental & social benefits
  - An optimal blending mandate level would encourage a level of biofuel use such that marginal social benefit equals marginal social cost
- Oil supply shock costs from BioTrans (in $/gallon of gasoline use) should be expected to be lower than the disruption cost components in the energy security premium of biofuels
  - Shock costs in BioTrans are confined to fuel markets and assume competitive markets
  - But disruption costs in Security Premium are *expected value (weighted by probability)*
  - BioTrans results offer more detail about timing of costs (by accounting for direct relationship between elasticity and length of run) and regional distribution
- Results from econometric analysis can help validate BioTrans model, inform benefits
  - Compare observed correlation between ethanol and gasoline prices with BioTrans implied results

4 – Relevance

- Energy security and resilience are founding objectives for biofuels
  - Project seeks to define and assess energy security metrics for alternative system configurations and market contexts to help guide strategic planning
- Project contributes to DOE Strategic Analysis Goals and Key Milestones
  - "provide context and justification for decisions at all levels by establishing the basis of quantitative metrics"
  - "Develop and maintain analytical tools, models, methods, and datasets to advance the understanding of bioenergy and its related impacts"
  - "By 2018, complete analysis on impact of advanced biofuels use on gasoline and diesel prices" [MYPP March 2016]
  - "By 2019, publish a multi-dimensional analysis that identifies and quantifies specific economic, environmental, and social benefits of a transition to a robust bioeconomy" [BETO Strategic Plan, December 2016]
- Relevance to bioenergy industry: a resilient biofuel supply chain will help maximize energy security benefits of biofuels and also promote economic sustainability for their participants
  - Resilience requires ability to weather oil and biomass supply shocks
  - Analysis tools developed in this project can help evaluate system benefits and costs of strategies to improve resilience (e.g., co-products, advanced biomass logistics, strategic stocks, feedstock flexibility at biorefinery, blending flexibility at refinery)

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5 – Future Work

- FY17:
  - Increased attention to biomass supply shocks
    - Biofuels help mitigate the costs of oil supply costs but the biomass feedstocks used to produce them also experience their own shocks (e.g., bad crops due to weather, pests)
    - Probability, magnitude and costs of biomass supply shocks need to be considered in making a full analysis of energy security impacts of biofuel
  - Web interactive tool to be hosted in KDF focused on energy security role of biofuels (FY17Q4)
    - Diagrams conveying multiple dimensions of energy security concept
    - Users will be able to interactively explore results from BioTrans supply shock analysis

- Beyond FY17 – Ideas for follow-on research:
  - Rigorous valuation of estimated price impact and volatility reduction benefits from biofuels
    - E.g. Combining empirical and analytical models
  - Implications (biofuel synergies & opportunities) of changing U.S. oil supply, transport & refining
    - E.g. BioTrans and TRIM
  - Analysis of market impacts & economic benefits of evolving RFS/RIN/Biofuel policies
  - Exploring how bio-products can improve resilience of bioenergy system

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Summary

- Overview:
  - Estimating biofuel benefits with a special focus on energy security and resilience, price effects
- Approach
  - Combines partial equilibrium modeling of markets and policies with selected empirical analysis of historical market data, and development of useful energy security metrics
- Technical Accomplishments/Progress/Results
  - Detailed exploration of the impacts of oil supply shocks under a variety market contexts (depiction of alternative domestic oil supply shares, regional insights)
  - Updated energy security premium estimates associated with biofuel replacing petroleum fuels
  - Econometric estimation of the relationship between volatility of biofuel and petroleum fuel prices based on historical market data
- Relevance
  - Measuring and communicating economic and social benefits (also potential risks) of further penetration of biofuels under various market and policy futures
  - Assessing impacts of biofuels on fuel expenditures by light-duty vehicle owners
- Future work:
  - Biomass supply shock analysis
  - Interactive web tool to communicate findings regarding energy security role of biofuels

Supplemental Slides

Summary of Responses to 2015 Peer Reviewers' Comments

- Comment: "This project tackles interesting questions, with a variety of modeling an econometric approaches. Model validation will be critical given ever-changing global and domestic oil and biofuel markets."
  - Response: "We (and BETO) agree that model validation is a key challenge and requirement for the success of their Analysis portfolio. We are actively engaged with BETO's efforts in model characterization and comparison including participation in the 2014 and 2016 Bioenergy Modeling Workshops"
- Comment: "This project combines traditional partial equilibrium economic modeling and empirical/econometric analysis of historical data. The two approaches together provide valuable insights on energy security. Among its strengths is its reliance on well-accepted economic theory and analysis. It can thus speak with credibility to the vast audience of conventional economists that dominate much of the dialogue in energy policy. It also provides a complementary perspective to that of the system dynamics modeling approach used in other projects within the analysis platform"
  - Response: "The relationship between BSM and BioTrans modeling teams became stronger during collaboration in the renewable super premium market assessment. By closely coordinating assumptions and developing a joint set of scenarios, result differences could be traced back to differences in modeling approaches and produce insights as to which kind of questions each model is best suited to answer"
- Comment: "It would be good for the audience to better understand how the methodologies applied to these forecasts compare to what EIA is doing"
  - Response: "EIA generates its energy market projections using the National Energy Modeling System (NEMS) which has a much larger scope than BioTrans. We use fully integrated NEMS cases as reference to benchmark some of the variables in BioTrans (e.g., gasoline supply curves and final fuel demand). The principle we follow is to make BioTrans consistent with EIA's NEMS projections but allow it to diverge from them (through elastic supply and demand curves) based on a more detailed and flexible representation of the biofuels supply chain."

Summary of Responses to 2015 Peer Reviewers' Comments

- Comment: "I don't see how the work is being related to the public policy space/is making impacts, particularly if the publications/deliverables are not available online."
  - Response: We will make a priority that our work becomes more visible and clearly linked to issues facing decision-makers in the policy space. For future work, we have proposed more of an outreach effort, including a visible website area and/or a workshop highlighting our results and related work by others, as well as the pursuit of high-visibility external publications. One major goal is to show how volatility and shocks influence the economic and social benefits of biofuels and to inform the research and policy community on how resilience strategies can enhance those benefits.
- Comment: "There would be much value in seeing planned future work integrated with the results of work to date in an interim report. The project appears to be developing numerous sub-analyses of the fuels and bioenergy market. However, the material and conclusions need to be periodically tied-up together so broader themes are easier to follow."
  - Response: We acknowledge the need to better tie up together the results and insights from the various tasks and modeling approaches we are using in this project. We have cited as one of our objectives for the future of the project to develop a website to host interim working papers and publications and to explain how all relate to the central topic of explaining and quantifying the economic and energy security benefits of biofuels.
- Comment: "The precipitous drop in oil prices and the increasing supply of domestic oil present ample opportunity for future analysis as will uncertainties around the RFS volumes."
  - Response: We will explore 1)the implications of increased domestic oil and gas supply for biofuels industry prospects and energy security contribution, 2) RFS-2 policy uncertainty, 3)biofuels in the context of low oil prices, 4) alternative vehicle stock projections

Publications, Patents, Presentations, Awards, and Commercialization

- Uria-Martinez, R., Brown, M., and P. Leiby (2015). “Exploring Alternative RFS-2 Futures: Barriers, Compliance Strategies and Fuel Market Welfare” Report. October, 2015.
- Uria-Martinez, R., Brown, M., and P. Leiby (2016). “Energy Security Role of Biofuels in Evolving Liquid Fuel Markets” Technical Report. October, 2016.
- Leiby, Paul N. and Rocio Uria-Martinez (2017) “"Biofuels Blends and Fuel Price Volatility - A Portfolio Analysis,“ ORNL Report, February.

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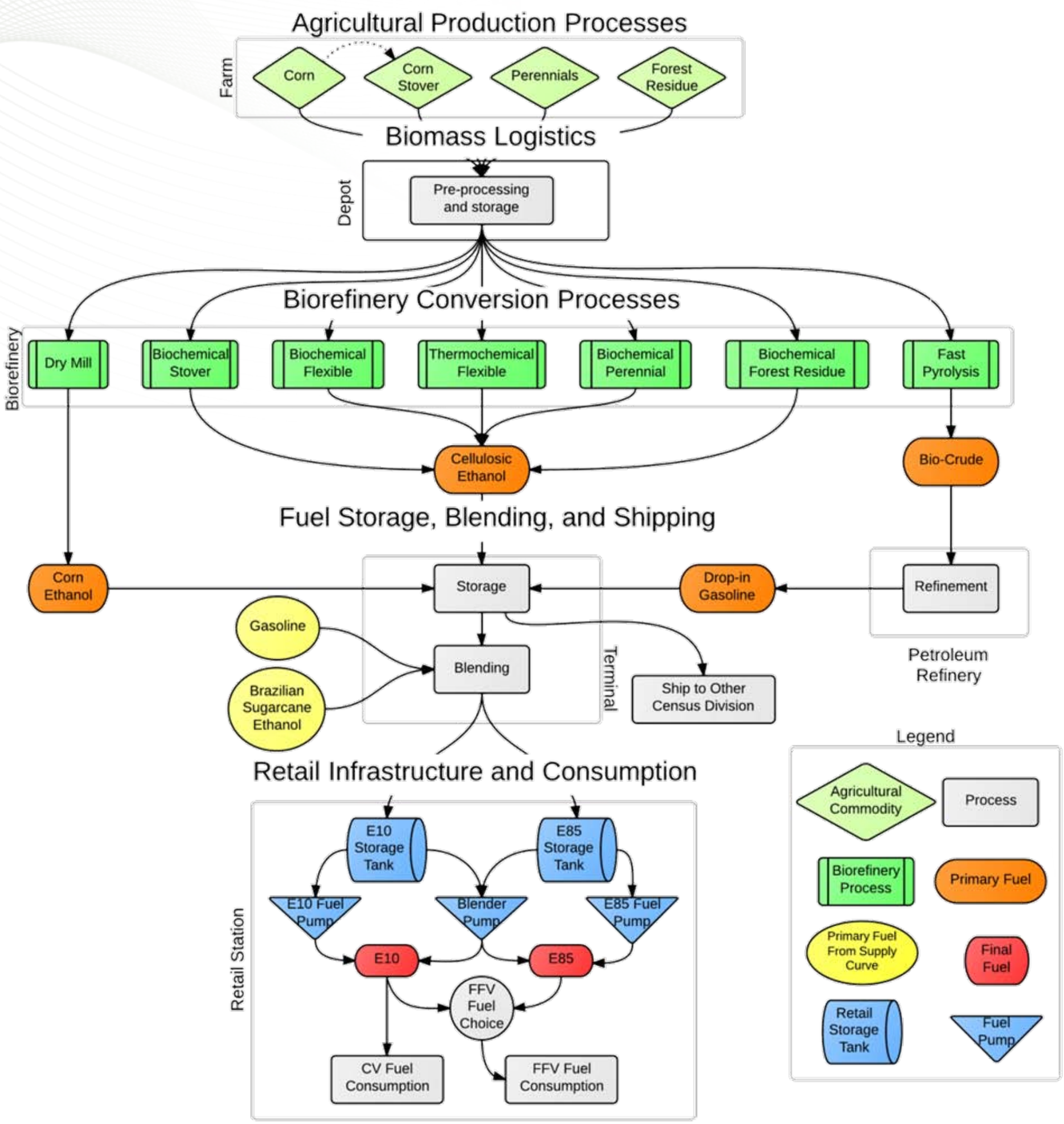
BioTrans Model Structure



- Classical economic model (nonlinear programming optimization, partial equilibrium)
  - Market clearing quantity-price combinations throughout the supply chain
  - Spatial and intertemporal equilibrium conditions are satisfied
- National scope, 30 years
  - Depicts transitions that depend on long-lived investments, expectations
- Regional disaggregation at census-division level
- Includes representative set of feedstocks and conversion processes, logistics, fuel retail, and fuel choice

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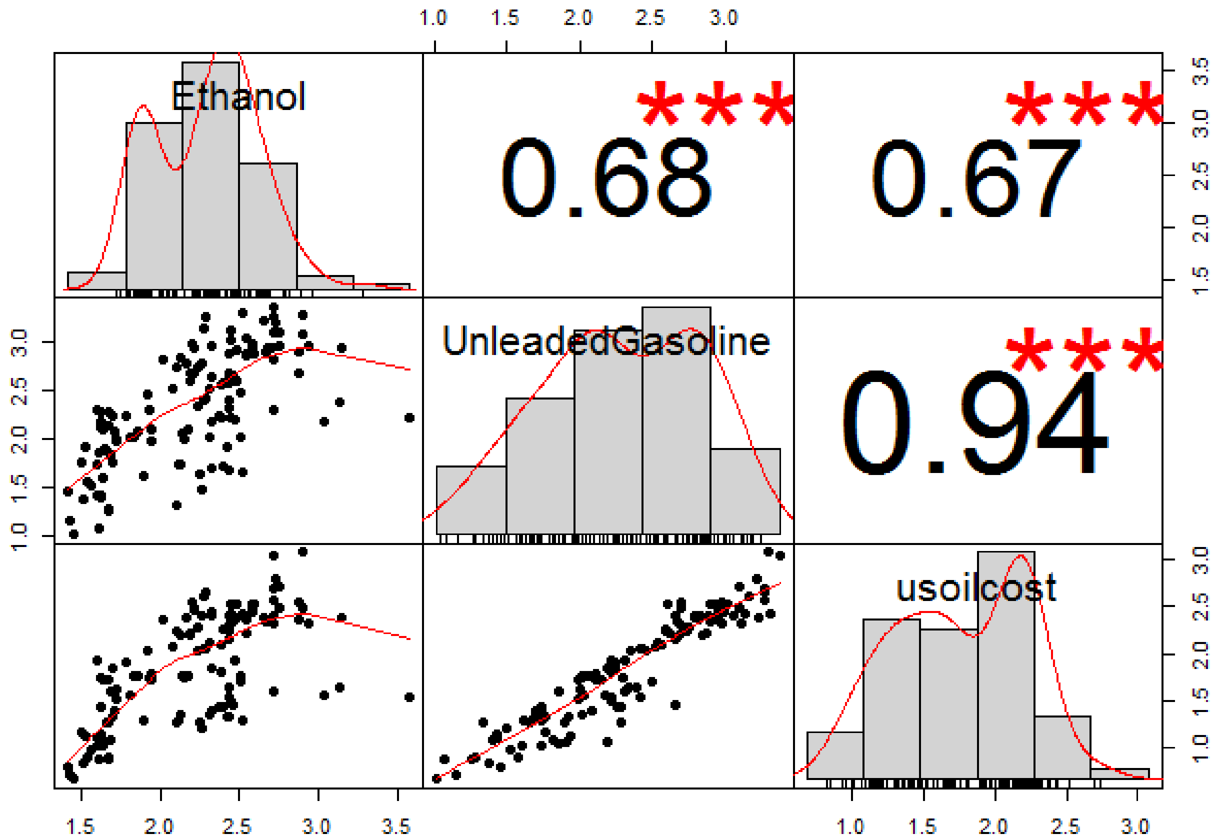
Task A. Matrix of "Factors promoting energy security" vs. "Energy Security Attributes," based on info from experts, stakeholders

Energy Security Attributes and Factors Revision: 2/20/2014

	Identified Attributes of Energy Security										
	Supply stability (avoid supply volatility or loss, resulting price spikes) (concern for DS)			**Energy price stability (concern for ΔPe, often due to ΔS)**		**Economic security (related to energy) (Ce, ΔY, ΔGDP)**				**Reduced importance of energy for National Security/Foreign Policy**	
Factors/Actions	"Resilience" of energy-feedstock supply (oil or substitute)	Supply-chain stability	Domestic-origin of supply	Short-run buffer supply availability	Flexibility of demand (through reduction or substitution [8])	Lower/acceptable energy cost burden (Ce = Pe*De)	Income stability for farmers	Economic stability/ market reliability for fuel producers	Lower GDP sensitivity to price shocks [3,8]	Military energy security: reliable military fuels at acceptable cost	Foreign–policy and National-security independence from energy [12]
o Fossil fuel/petroleum consumption displacement [3,5,8]	X			X					X		x
Seek substitute fuel with more stable supply and lower price volatility [5a Kiefer]		X				X					
o Energy import reduction									X		
Oil import reduction			X								
Other fuel import reduction (including biofuels imports)			X								
o Expanded fuel choice options for consumers at pump (e.g. petroleum fuels and biofuels)		X			X				X		
o Energy crop supply resilience, hardy energy crops		X					X	X			
Crop stress tolerance: drought tolerance; heat tolerance; salt tolerance [1]		X					X	X			
Low input (water or fertilizer) crops [1]		X					X				
High yield crops		X					X	X			
Crops suitable for an extended range of lands		X						X			
Feedstock and policy that is resilient in face of climate/weather variability and risk		X									
o Non-food crop based fuels avoiding volatile interactions with food markets						X		X			
o Conversion process modularity and flexibility	X	X									
o Storage/Inventories to smooth supply/demand variations				X							
Cost-effective storage (store-ability) of biomass				X							
Ability to store as stand in field or forest across seasons1				X							
Ability to store more cheaply/longer given preprocessing				X							
o Fuel supply chains resistant to disasters (weather; natural; political)	X	X					X	X			
o Reduction of economic sensitivity to energy price shocks											
Reduction of oil use (cost share in economy, or activity)						X			X		
Diversification of sources, limiting budget exposure											
Biorefinery flexibility in terms of outputs (co-products)								X			
o Energy infrastructure reliability		X									
o Greater flexibility and price stability through fuel compatibility with existing infrastructure [10,2]											
o Flexibility and price stability through flexible policy incentives (avoid regulatory risk)								X			
o Supply stability through policy stability [8,12]		X						X			

Motivation:
Observation: Ethanol Price Levels are Correlated, but Imperfectly with Oil. Fuel Price *Changes* Even Less So

Correlations Among Monthly Fuel Prices
(Ethanol, Gasoline, CrudeOil, 2006M01 – 2016M07



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