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DOE Bioenergy Technologies Office (BETO) 2015 Project Peer Review

4.1.1.50 High Level Techno-Economic Analysis of Innovative Technology Concepts

3-24-2015

Analysis & Sustainability

Pacific Northwest National Laboratory: Sue Jones

Iowa State University: Mark Wright

Goal Statement

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- **GOAL: Enable R&D of economically viable biomass derived liquid fuels by:**
  - Performing **rapid screening** techno-economic analysis (**TEA**) for potential new conversion processes
  - Identifying **gaps** and **opportunities** for these processes
  - Quantifying product cost **uncertainty** for these processes

- **This project directly supports BETO's goal to:**
  - *"Encourage the creation of a new domestic bioenergy and bioproduct industry."* (Nov. 2014 MYPP)

Quad Chart Overview

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Timeline

- Start: October 1, 2012
- End: December 31, 2014
- Status: Projected Completed

Budget

	Total Costs FY 10 –FY 12	FY 13 Costs	FY 14 Costs	Total Planned Funding (FY 15)
DOE Funded	$200k	$200k	$125k	$0
Project Cost Share (Comp.)*	$0	$0	$0	$0

Barriers

- Barriers addressed
  - **At-A**: Comparable, transparent and reproducible analysis
  - **Im-F**: Cost of production
  - **It-E:** Engineering modeling tools

Partners

- **PNNL** (43%): TEA
- **Iowa State University** (57%): TEA & uncertainty analysis
- Project management – ISU subcontracted to PNNL

Project Overview

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- **History**: 3 year project
  - FY 12 & 13 focused on producing **8** high level **TEAs**
  - FY14 focused on **4 uncertainty analysis** cases
- **Context**
  - BETO's portfolio expanded to include **hydrocarbon fuels**
  - Need for **quick** preliminary **analysis** of candidate pathways
  - Need to put **error bars** on the subsequent costs estimates
- **Objective:** support BETO analysis for enabling the production of advanced biofuels
  - **Rapid screening** economics of 8 processes of interest
  - **Leverage** open literature, experimental data and analysis skills from **both institutes**
  - Apply **uncertainty analysis** to TEA results

Approach (Technical)

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- **Overall technical approach**
  - **TEA:** ISU and PNNL lead on specific pathways, then exchange data and results for intermediate and final reviews to ensure consistency
  - **Uncertainty analysis:** ISU lead, PNNL provided variance input and review
  - Model in Chemcad and costs in Excel using standard BETO assumptions
    - One exception: used higher Lang factors to reflect high level analysis
- **Critical success factors**
  - ID promising **new pathways** & **data gaps** and highlight **uncertainty**
  - **Publish** results for use by others
- **Potential challenges**
  - Ensure **consistent** and **appropriate assumptions**: defined technical basis and economic assumptions at start of project & reviewed with BETO
  - **Value to BETO**: reviewed proposed pathways with BETO the each year prior to starting analysis
  - Key research and cost **information availability**: engage researchers at both labs as well as literature data (more detail in upcoming slides)

Approach (Management)

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- **Overall Management Approach**
  - **Project Management Plan** (PMPs) in place indicating scope, budget and schedule
  - **Annual Operating Plans** (AOPS) prepared prior to each fiscal year
    - Details quarterly **milestones** and **deliverables**
    - **Go/No-go** point to assess project value and direction
  - **Quarterly reporting** to BETO (written and regularly scheduled telecons)
- **Critical success factor**
  - **Timely subcontracting**: early scheduling with both entities' contracting offices facilitated quick completion
- **Potential challenges**
  - **Researcher proximity**: scheduled regularly occurring calls & data exchanges
  - **Data compatibility**: used same software platforms

Technical Accomplishments: TEA Summary Results (FY12&13)

- Each pathway included catalytic upgrading to fuel blendstocks:
  - ***In situ* catalytic pyrolysis*** (combined pyrolysis & vapor upgrading)
  - ***Ex situ* catalytic pyrolysis*** (fast pyrolysis with vapor upgrading in a separate reactor)
  - **Hydropyrolysis*** (catalytic pyrolysis in a hydrogen atmosphere)
  - **Fast pyrolysis*** with **bio-oil fractionation** to fuels
  - **Catalytic pyrolysis*** of lipid extracted algae remnants
  - **Fast pyrolysis*** with **vapor fractionation** for fuels and chemicals
  - **Syngas fermentation** to ethanol and upgrading to distillate fuels
  - **Syngas to mixed alcohols** and upgrading to distillate fuels
- **Base case** MFSP mostly in the **$5-7/gallon** range (feedstock cost $80/ton)
- All cases needed **improved yields** and **reduced capital** and **operating** to meet **$3/gge**

* Presented at 2013 peer review

Syngas conversion to mixed alcohols and alcohol upgrading to distillates

- Processes **modeled** in Chemcad
- Cost model in Excel using discounted cash flow analysis consistent with all BETO analysis
- Resulting in a Minimum Fuel Selling Price **(MFSP)** – the value at which the NPV is zero for a given rate of return
- Leveraged existing models when available

Technical Accomplishments: Syngas to Distillates Base Case

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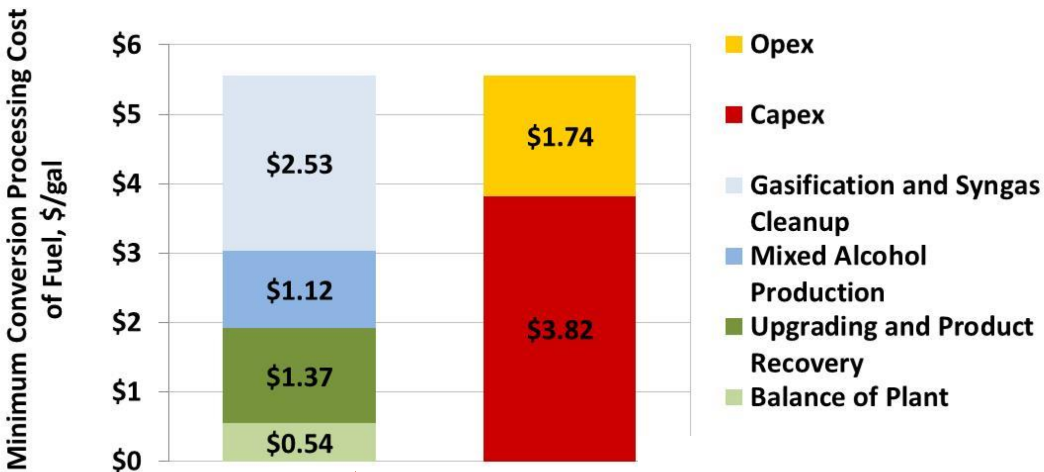
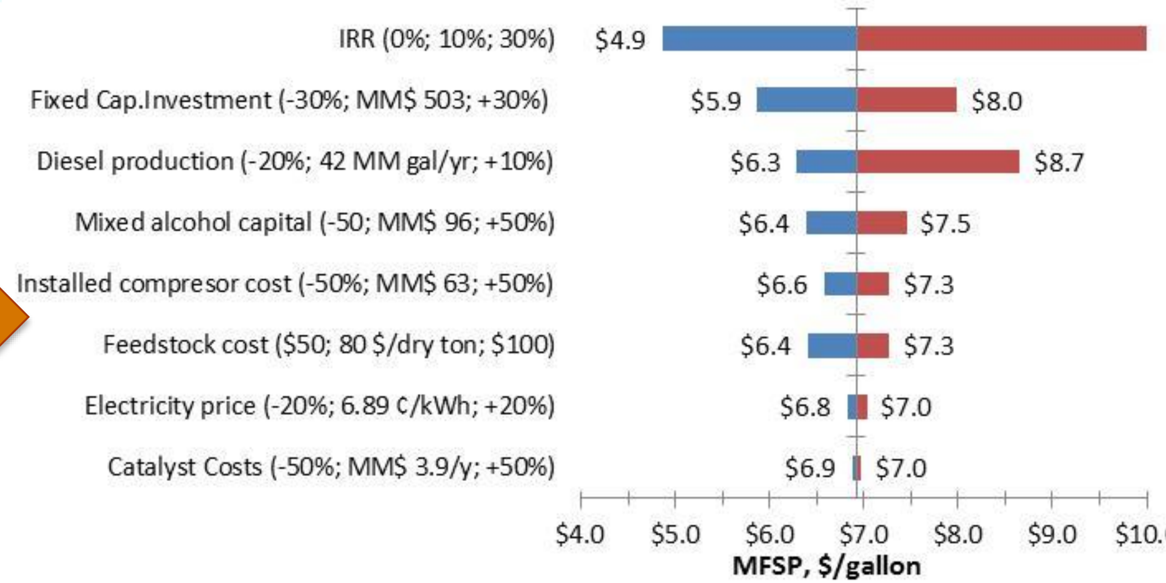
Conversion Contribution (ex feedstock) by Area
Gasification to syngas, alcohol synthesis and upgrading



Cost contributions by processing area (excludes feedstock cost)

Tornado Plot sensitivity analysis used to highlight cost impacts (including feedstock)



Technical Accomplishments: Uncertainty Analysis

- **FY14 Focused on Uncertainty Analysis**
  - **Go/No-Go** discussion led to new scope
    - Additional new pathways not a priority for BETO
    - Strong need to understand the error bars around the MFSP

- Apply **Monte Carlo** type uncertainty to select FY12 and FY13 that are the **most relevant** to the Office
  - *In situ* catalytic pyrolysis and upgrading to fuel blendstocks
  - *Ex situ* catalytic pyrolysis and upgrading to fuel blendstocks
  - Syngas to alcohols and upgrading to distillates - base case
  - Syngas to alcohols and upgrading to distillates - target case

Technical Accomplishment: Uncertainty Methodology

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Syngas to Distillates Scenario Method

Excel
Collect data for key parameters

→

Mathematica
•Find key parameters best fit distributions
•Use Monte Carlo method to generate random data set per best fit distribution

→

CHEMCAD
Conversion sensitivity:
•Syngas → alcohols
•Alcohols → hydrocarbons

↓

Mathematica
Linearly regress conversion results

←

Excel/VBA
•Financial analysis
•Calculate MFSP for each input

←

Mathematica
•Calculate MFSP error bars & distribution
•Calculate key parameters' impact

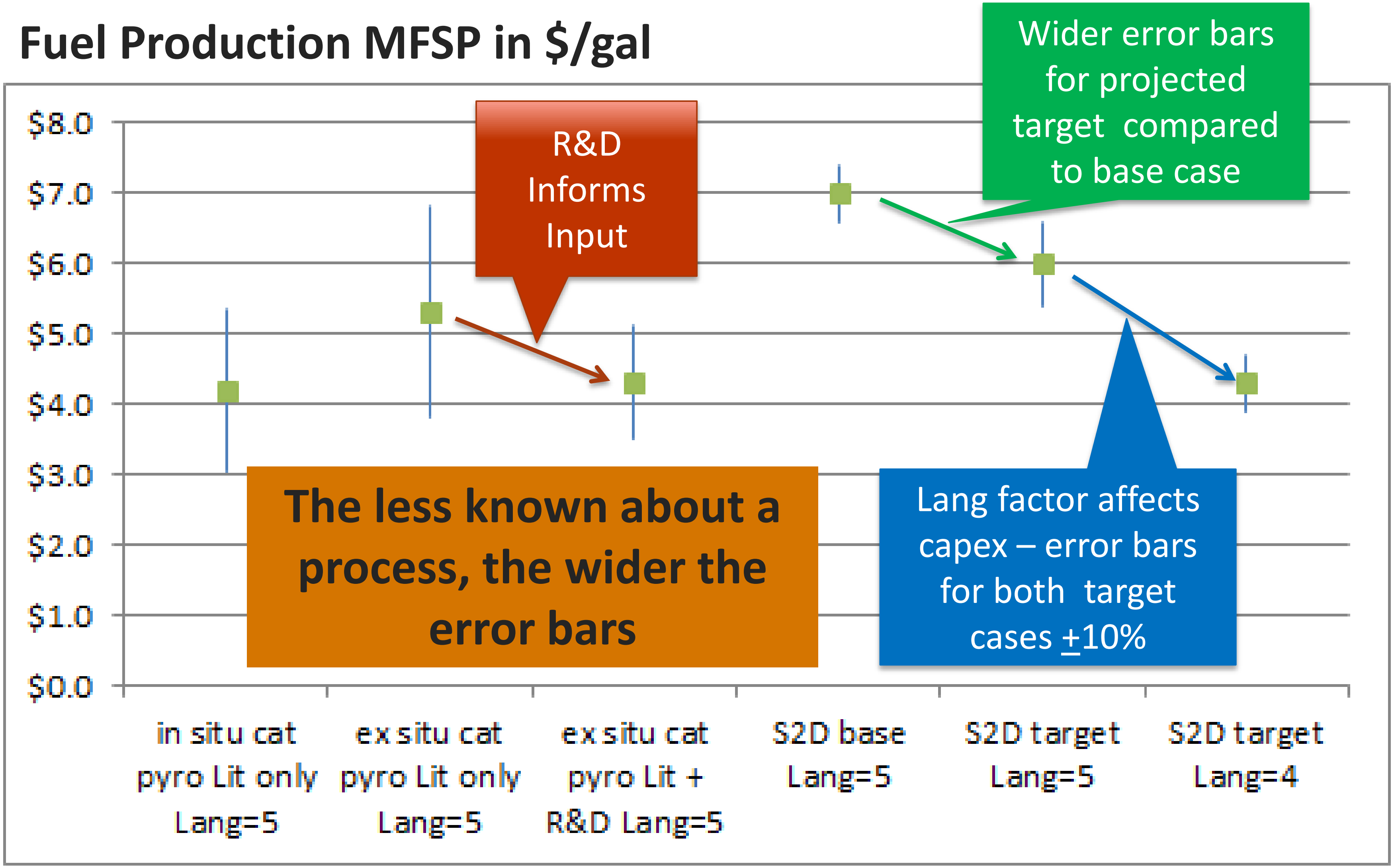
- http://www.wolfram.com/mathematica/
- http://www.chemstations.com

Technical Accomplishments: Uncertainty Variables

- **Parameter distributions considered:**
  - **Yields** by processing area
  - **Capex** (by major pieces of equipment)
  - Equipment configurations **(# up vs. scale up)**
  - **Catalyst** cost and consumption
  - **Hydrogen** cost and consumption
  - **Power** requirements
  - **Feedstock** costs
  - Historic **utility price variation**

Technical Accomplishments: Uncertainty Results

Fuel Production MFSP in $/gal



Technical Accomplishments: Overall Outcome

- **Quantifying uncertainty is not simple**, and like the underlying TEA, requires constant dialogue with researchers
- Single point **MFSP** and one-variable-at-a-time tornado plots **may not show all impacts** when comparing dissimilar processes (e.g. catalytic pyrolysis vs. syngas to fuels)
- **Take-away:** when limited data are available, **comparing pathways** solely on single point MFSP relative economics **can be risky**

Technical Accomplishments: Project PMP Milestone Progress

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Title/Description	Due Date	Completed
Finalize common methodologies and select processes for comparison to \$3/gal target	Dec-11	On-time
Complete first high level TEA and compare to \$3/gal target	Mar-12	On-time
Complete 2nd and 3rd high level TEA and compare to \$3/gal target	Jun-12	On-time
Finalize all TEAs and compare to \$3/gal target; submit final report	Sep -12	On-time
Review pathways choices with BETO	Dec-12	On-time
Complete 5th high level TEA	Mar-13	On-time
Complete 6th and 7th high level TEAs	Jun-13	On-time
Finalize all TEAs and submit final report	Sep-13	On-time
Review pathways choices with BETO	Dec-13	On-time
Go/No-Go - changed scope from TEA to uncertainty analysis	Feb-13	On-time
Complete first uncertainty analysis	Jun-14	On-time
Complete second uncertainty analysis	Sep-14	On-time
Complete 3rd and 4th uncertainty analysis and submit final report	Dec-14	On-time

Relevance

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- **Impact on BETO 2012- 2013 Goals**:
  - Initial **TEA work supported** *"By 2013, select and complete techno-economic modeling and set goals and targets for at least two hydrocarbon pathways"* (Nov 2012 MYPP & May 2013 MYPP) – this project lead into subsequent, separate work by PNNL & NREL to assess pathways in more detail and fuel cost reduction opportunities
- **Impact on BETO 2014 Goals**:
  - *"Market & Impact Analysis:* ***Identify, quantify,*** *and* ***evaluate uncertainty*** *and* ***risk of biofuels****"* (July 2014 MYPP) – this work enhances the typical single point MFSP analysis and single variable sensitivity analysis
  - *"Technology and Resource Assessment:* ***Comparative*** *technical and economic* ***assessment of biofuels****"* (July 2014 MYPP)
- **External use of this work:**
  - Results made public in **peer reviewed publications**
  - Studies can be used by industry & academia to start their own evaluations

Future Work

- **Project ended 12/31/14**
  - **Going forward:** working with BETO on if/how to apply uncertainty analysis methods to show error bars around fuel production costs for other TEA efforts

Summary

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Overview: **Rapid TEA** of biofuel processes of interest to BETO

Approach: Iterative, ISU & PNNL share inputs & review results

Technical Accomplishments/Progress/Results

- FY12-13: **8 TEAs** completed
- FY14: **4** TEAs analyzed for **uncertainty**
- Provided input to the FY12-13 BETO new pathways analysis
- Uncertainty analysis methodology applicable to other projects
- **3 peer reviewed journal publications** (TEA only) and **2 more** being prepared (TEA + uncertainty analysis)

Relevance: by assessing conversion processes this project aligns with BETO's ultimate mission to reduce dependence on petroleum and achieve cost parity with conventional transportation fuels

Future work: **project completed**

Status since 2013 Review: Go/No-Go outcome redirected focus from TEA to uncertainty analysis thus better meeting BETO's needs

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Yihua Li
Tristan Brown

Uncertainty Analysis:
Mark Wright (lead)
Boyan Li
Longwen Ou

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Additional Slides

- Response to comments from 2013 Review
- Publications and presentations
- TEA Assumptions
- Example of qualitative process comparison and gaps
- Density functions and uncertainty plots
- List of abbreviations

Responses to Previous Reviewers' Comments

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- **2013 Review Comment:** "Tornado plots…as summarized in this project offer little insight about the comparative advantages of different technology pathways."
- **Response:** This was addressed by substituting more meaningful sensitivity ranges for the fixed percentages initially used for each key input (e.g. catalyst life, capital cost) specific to each technology and adding Monte Carlo uncertainty analysis to further define differences.

- **FY14 Go/No-Go:**
  - **Criteria:** project relevance to current BETO needs
  - **Outcome:** new pathway analysis no longer needed. BETO did however, have a need for a way to put error bars around TEA results. Hence, scope was changed to introduce a Monte Carlo type uncertainty analysis.

Publications and Presentations

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- **Publications**
  - R. Tilakaratne, T. Brown, Y. Li, G. Hu, and R. Brown, "Mild catalytic pyrolysis of biomass for production of transportation fuels: a techno-economic analysis," Green Chemistry, vol 16, 627-636, 2014.
  - T. Brown, R. Tilakaratne, R. Brown, and G. Hu, "Techno-economic analysis of biomass to transportation fuels and electricity via fast pyrolysis and hydroprocessing", Fuel, 463-469, 2013.
  - Y. Zhang, T. Brown, G. Hu, and R. Brown, "Technoeconomic analysis of mono-saccharide production via biomass fast pyrolysis", Bioresource Technology, 358-365, 2013.
  - 2 additional drafts underway related to uncertainty analysis
- **Presentations**
  - Presented as the special topic for the January 2015 Analysis and Sustainability call between BETO HQ and the national laboratories

TEA Assumptions

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Assumptions regarding stream factor and conservative Lang factor to reflect preliminary nature of the analysis

Cost year	$US 2011	**Loan interest**	8%
Feedstock	$60/dry US ton for algae remnant $80/dry US ton for pyrolysis wood $75/dry US ton for gasification wood	**MACRS Depreciation**	General plant: 7 years Steam plant: 20 years
Stream factor	90%	**Rate of Investment (after tax)**	10%
Plant Life	30 years	**Lang factor**	5
Construction	2.5 years	**Working capital**	15% of FCI
Startup time	0.5 years	**Property tax and Insurance**	2% of FCI
Income tax rate	39%	**Maintenance**	2% of FCI
Equity	40%	**Gen & Admin overhead**	95% of labor
Loan term	10 years	**Feedstock Cost for Uncertainty Analysis**	$80/dry ton

Example Research Gaps & Qualitative Comparison Table

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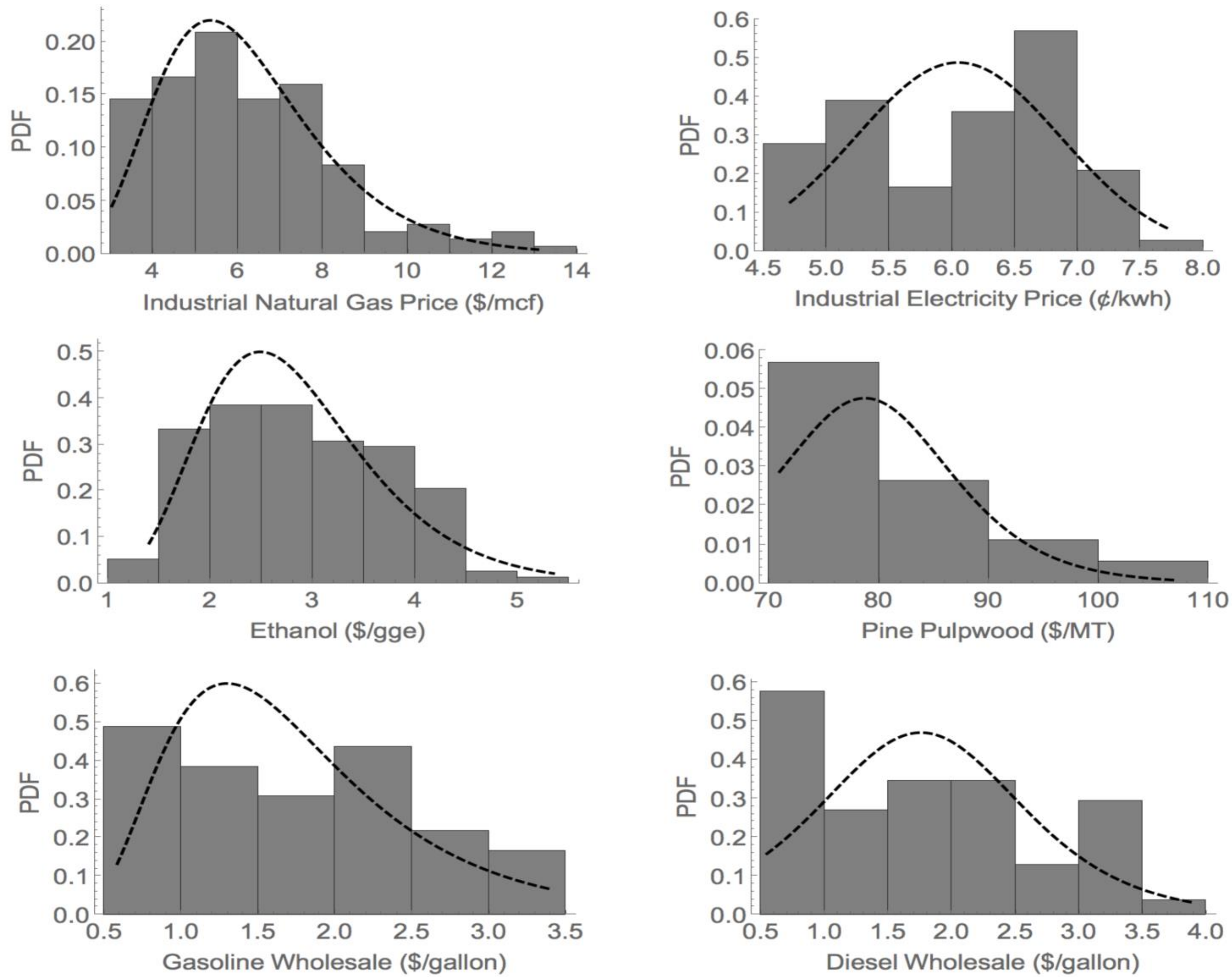
	Uncatalyzed Fast Pyrolysis and liquid phase upgrading	Case 1: *In situ* vapor phase catalytic pyrolysis	Case 2: *Ex situ* vapor phase catalytic pyrolysis
Bio-oil Production	Single reactor High CW usage required by rapid quench system & no heat recovery	Single reactor Possible heat recovery and reduced CW demand	Two reactors Possible heat recovery and reduced CW demand
Intermediate Bio-oil quality	~50% oxygen plus associated water, More difficult to upgrade	Lower oxygen content in product, easier to upgrade	Lower oxygen content, easier to upgrade. Two reactors allow more control over gas/liquid/solid, possible lower catalyst inventory than in-situ
Upgrading to hydrocarbon Capital	At least two upgrading reactors in series, the second one is very large Reactors see 100% of the produced water, plus feedstock moisture	Potentially a single, smaller upgrading reactor Reactors see small fraction of produced water	Potentially a single, smaller upgrading reactor Reactors see small fraction of produced water
Upgrading catalyst life	Still short	Potentially longer, depends upon degree of vapor upgrading	Potentially longer, depends upon degree of vapor upgrading
Waste water treatment	No wastewater from fast pyrolysis. Wastewater from upgrading to hydrocarbons very low in organics	WW could have high concentration of dissolved organics	WW could have high concentration of dissolved organics
Hydrocarbon Yield	Highest so far	Lower than conventional pyrolysis and upgrading so far	Lower than conventional pyrolysis and upgrading so far

Density Function Examples



Syngas to Distillates Example

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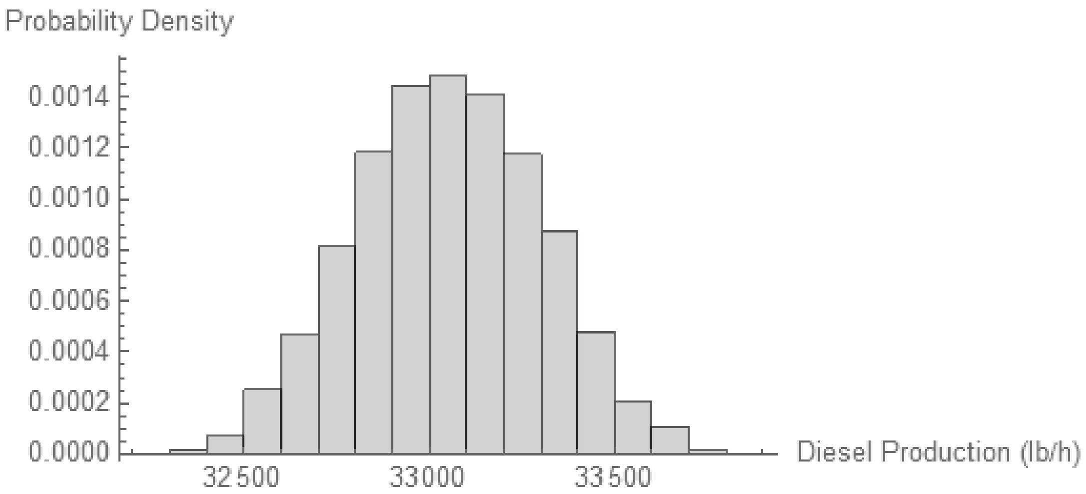
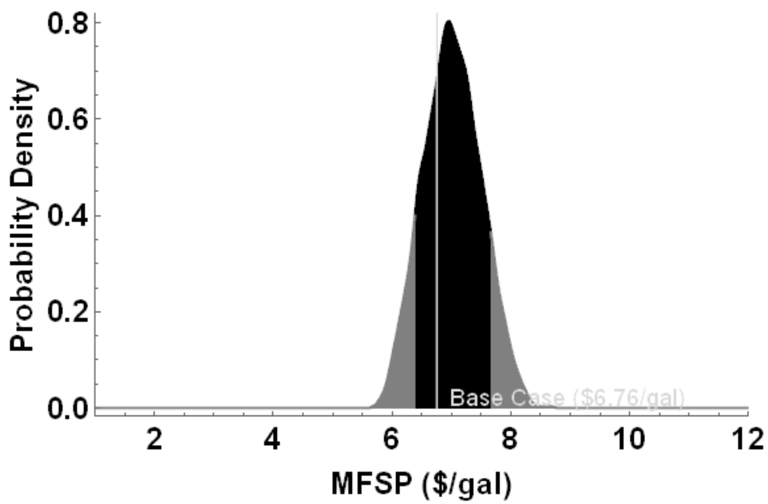
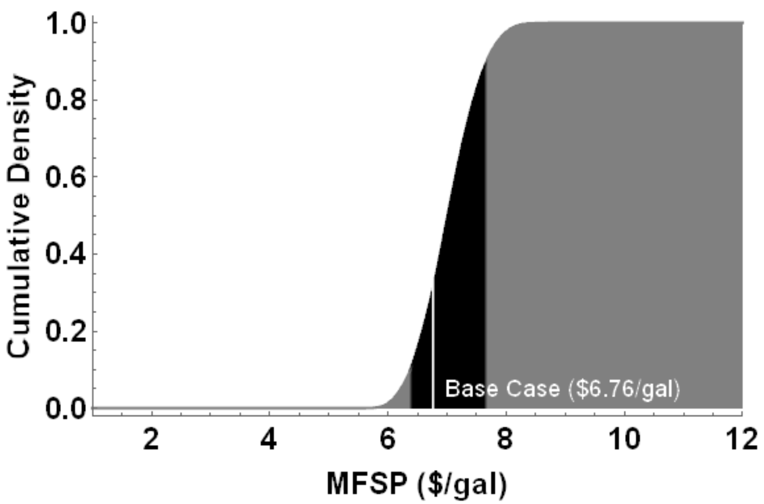
- Diesel production probability distribution for syngas to distillates case scenarios







- Minimum Fuel-Selling Price (MFSP) probability (left) and cumulative (right) distributions for syngas to distillates with high Lang factor.

Parameter Uncertainty

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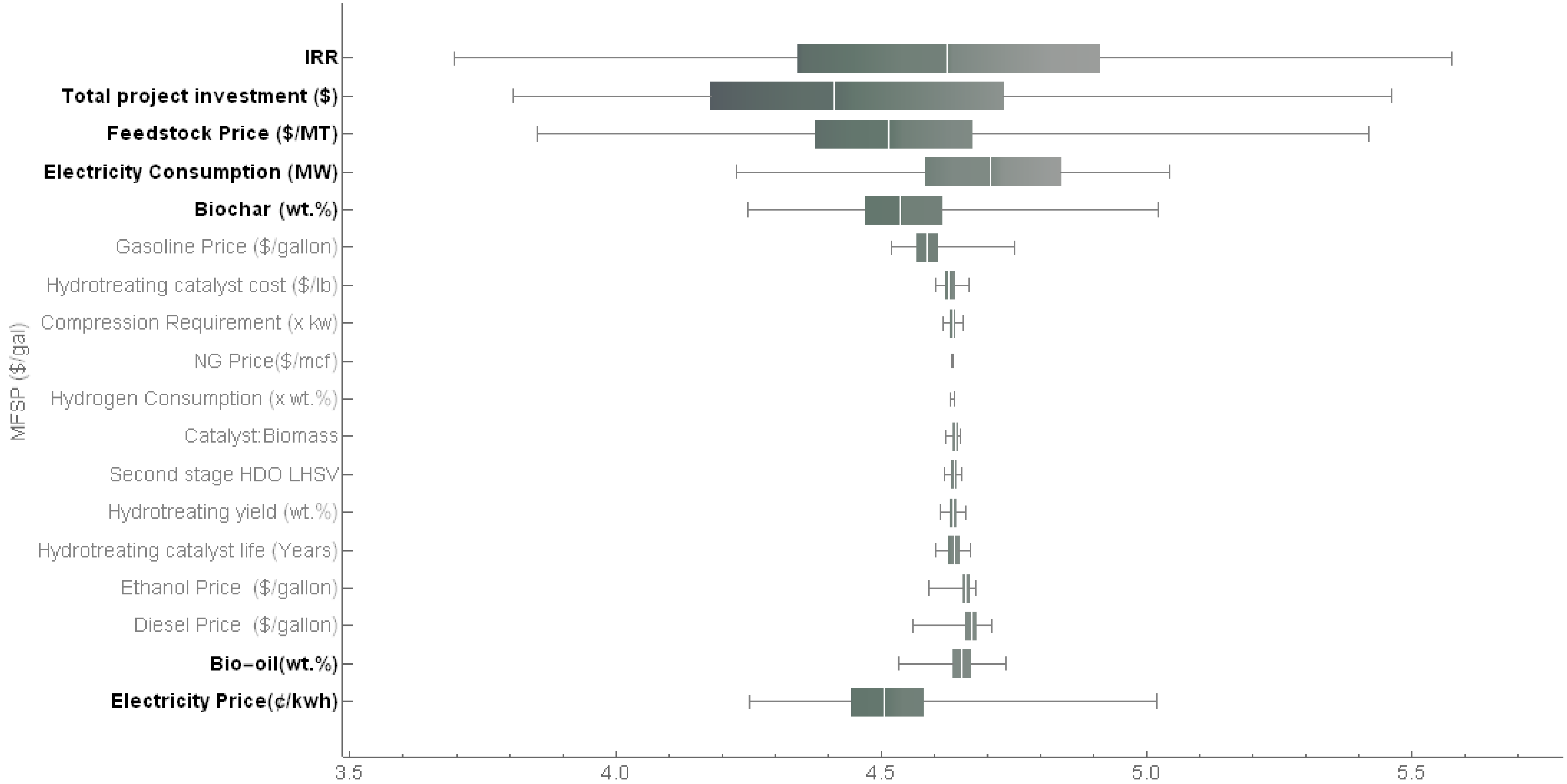

Ex-situ catalytic pyrolysis parameter uncertainty impact on the MFSP. Gates indicate min/max MFSP range; boxes indicate 0.25-0.75 quantiles of the MFSP; white vertical lines show the mean MFSP value. Bold legends indicate significant ($p<0.05$) parameters.

Abbreviations and Acronyms

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- AOP: annual operating plan
- BETO: Bioenergy Technologies Office
- GGE: gasoline gallon equivalent
- ISU: Iowa State University
- LANG: ratio of total capital investment to purchased equipment cost
- LCA: life-cycle analysis
- MFSP: minimum fuel selling price
- MYPP: multi-year program plan
- NPV: net present value
- PMP: project management plan
- TEA: techno-economic analysis