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

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Iowa State University: Mark Wright

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Goal Statement

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

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

**Budget**

<table>
<thead>
<tr>
<th></th>
<th>Total Costs FY 10 – FY 12</th>
<th>FY 13 Costs</th>
<th>FY 14 Costs</th>
<th>Total Planned Funding (FY 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE Funded</td>
<td>$200k</td>
<td>$200k</td>
<td>$125k</td>
<td>$0</td>
</tr>
<tr>
<td>Project Cost Share (Comp.)*</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
</tbody>
</table>

**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

**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
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)
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
Technical Accomplishments: Example TEA Results

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

Cost contributions by processing area (excludes feedstock cost)

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

**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**
- Calculate MFSP error bars & distribution
- Calculate key parameters’ impact

**Excel/VBA**
- Financial analysis
- Calculate MFSP for each input

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Syngas to Distillates Scenario Method

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[http://www.chemstations.com](http://www.chemstations.com)
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

- R&D Informs Input
- The less known about a process, the wider the error bars
- Wider error bars for projected target compared to base case
- Lang factor affects capex – error bars for both target cases ±10%
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.
<table>
<thead>
<tr>
<th>Title/Description</th>
<th>Due Date</th>
<th>Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finalize common methodologies and select processes for comparison to $3/gal target</td>
<td>Dec-11</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete first high level TEA and compare to $3/gal target</td>
<td>Mar-12</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete 2nd and 3rd high level TEA and compare to $3/gal target</td>
<td>Jun-12</td>
<td>On-time</td>
</tr>
<tr>
<td>Finalize all TEAs and compare to $3/gal target; submit final report</td>
<td>Sep -12</td>
<td>On-time</td>
</tr>
<tr>
<td>Review pathways choices with BETO</td>
<td>Dec-12</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete 5th high level TEA</td>
<td>Mar-13</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete 6th and 7th high level TEAs</td>
<td>Jun-13</td>
<td>On-time</td>
</tr>
<tr>
<td>Finalize all TEAs and submit final report</td>
<td>Sep-13</td>
<td>On-time</td>
</tr>
<tr>
<td>Review pathways choices with BETO</td>
<td>Dec-13</td>
<td>On-time</td>
</tr>
<tr>
<td><strong>Go/No-Go</strong> - changed scope from TEA to uncertainty analysis</td>
<td>Feb-13</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete first uncertainty analysis</td>
<td>Jun-14</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete second uncertainty analysis</td>
<td>Sep-14</td>
<td>On-time</td>
</tr>
<tr>
<td>Complete 3rd and 4th uncertainty analysis and submit final report</td>
<td>Dec-14</td>
<td>On-time</td>
</tr>
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</table>
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.

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
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
Acknowledgements

▶ Bioenergy Technologies Office – Alicia Lindauer

**PNNL TEAM**
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Sue Jones
Aye Meyer
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Kriston Brooks

**ISU TEAM**
Robert Brown

**TEA:**
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Longwen Ou
Chamila Thilakaratne
Yihua Li
Tristan Brown

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

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

Publications

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

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value/Detail</th>
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<tbody>
<tr>
<td>Cost year</td>
<td>$US 2011</td>
</tr>
<tr>
<td>Loan interest</td>
<td>8%</td>
</tr>
<tr>
<td>Feedstock</td>
<td>$60/dry US ton for algae remnant</td>
</tr>
<tr>
<td></td>
<td>$80/dry US ton for pyrolysis wood</td>
</tr>
<tr>
<td></td>
<td>$75/dry US ton for gasification wood</td>
</tr>
<tr>
<td>MACRS Depreciation</td>
<td>General plant: 7 years</td>
</tr>
<tr>
<td></td>
<td>Steam plant: 20 years</td>
</tr>
<tr>
<td>Stream factor</td>
<td>90%</td>
</tr>
<tr>
<td>Rate of Investment (after tax)</td>
<td>10%</td>
</tr>
<tr>
<td>Plant Life</td>
<td>30 years</td>
</tr>
<tr>
<td>Lang factor</td>
<td>5</td>
</tr>
<tr>
<td>Construction</td>
<td>2.5 years</td>
</tr>
<tr>
<td>Working capital</td>
<td>15% of FCI</td>
</tr>
<tr>
<td>Startup time</td>
<td>0.5 years</td>
</tr>
<tr>
<td>Property tax and Insurance</td>
<td>2% of FCI</td>
</tr>
<tr>
<td>Income tax rate</td>
<td>39%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>2% of FCI</td>
</tr>
<tr>
<td>Equity</td>
<td>40%</td>
</tr>
<tr>
<td>Gen &amp; Admin overhead</td>
<td>95% of labor</td>
</tr>
<tr>
<td>Loan term</td>
<td>10 years</td>
</tr>
<tr>
<td>Feedstock Cost for Uncertainty</td>
<td>$80/dry ton</td>
</tr>
<tr>
<td>Analysis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Uncatalyzed Fast Pyrolysis and liquid phase upgrading</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td><strong>Bio-oil Production</strong></td>
<td>Single reactor High CW usage required by rapid quench system &amp; no heat recovery</td>
</tr>
<tr>
<td><strong>Intermediate Bio-oil quality</strong></td>
<td>~50% oxygen plus associated water, More difficult to upgrade</td>
</tr>
<tr>
<td><strong>Upgrading to hydrocarbon Capital</strong></td>
<td>At least two upgrading reactors in series, the second one is very large Reactors see 100% of the produced water, plus feedstock moisture</td>
</tr>
<tr>
<td><strong>Upgrading catalyst life</strong></td>
<td>Still short</td>
</tr>
<tr>
<td><strong>Waste water treatment</strong></td>
<td>No wastewater from fast pyrolysis. Wastewater from upgrading to hydrocarbons very low in organics</td>
</tr>
<tr>
<td><strong>Hydrocarbon Yield</strong></td>
<td>Highest so far</td>
</tr>
</tbody>
</table>
Density Function Examples

- Industrial Natural Gas Price ($/mcf)
- Industrial Electricity Price ($/kwh)
- Ethanol ($/gge)
- Pine Pulpwood ($/MT)
- Gasoline Wholesale ($/gallon)
- Diesel Wholesale ($/gallon)
Syngas to Distillates Example

- 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.
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

- 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