Strategies for Co-processing in Refineries

Techno-economic & Refinery Impact Analysis

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Outline

• Introduction

• Refinery LP Model for Refinery Impact Analysis

• Co-Processing at Mild Hydrocracking Unit

• Co-Processing at Fluidized Catalytic Cracking Unit

• Discussions and Future Plan
Co-Processing Value to Bio-Refiner

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**Refinery Integration – Co-Processing**

- **Biomass**
- **Conversion**
  - Bio-oil
  - Biocrude
- **Hydroprocessing**
  - Hydrotreated Biofuel
- **Separation**
- **Product Blending**
  - Fuel Blends

**Raw Insertion**

**Co-Processing**

**Crude Distillation Unit**

**Upgrading**

**Blending**

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**Potential Cost Saving at Bio-Refinery**

(upgrading at a standalone biorefinery vs an existing petroleum refinery)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Reduction in MFSP ($/gge)</td>
<td>0.83</td>
<td>0.65</td>
</tr>
<tr>
<td>MFSP w/o SCR ($/gge)</td>
<td>4.28</td>
<td>3.11</td>
</tr>
</tbody>
</table>

Co-processing intermediate bio-oil or biocrude at an existing petroleum refinery has the potential to significantly reduce CAPEX and therefore minimum fuel selling price (MFSP) of a bio-refinery.
LP Model to Assess Refinery Impacts

- Biogenic Carbon
- Diesel Production
- Less Sulfur
- Less Metals


➢ A Bird’s Eye View of Full Refinery Linear Programming Optimization in Aspen PIMS

- Process Units
- LP models
- Property Blending
- LP models

- Crude
- Intermediates
- Butane
- LPG
- Gasoline
- Jet
- Diesel
- Fuel Oil
- Utilities
- Additives

Objective = Maximize Profits
I. Sales Revenues 100k
II. Raw materials (70k)
III. Utilities (10k)
IV. Additives (5k)
Refiner’s Margin 15k

➢ The economic value of co-processing biomass intermediates can be evaluated by
- comparing the gross margins of a petroleum refiner before and after adding bio-oil/biocrude
- comparing the break-even value of bio-oil/biocrude to petroleum refiner and its minimum selling price at bio-refinery.
LP Model to Assess Refinery Impacts

✓ Biogenic Carbon  ✓ Diesel Production  ✓ Less Sulfur  ✓ Less Metals


Model Inputs

• Mass balance and key properties of co-processing from experimental data
• Process model and assay data of petroleum refinery from Aspen PIMS Gulf Coast Example
• Process constraints
• Fuel specification
• Feed and Product Slates
• Unit capacity

Model Outputs

Gross margin
Break-even value
Blending constraints
Mass/Energy Balance
Basis for LCA


Refinery Analysis Inputs for SCR Project

- Refinery configuration and unit capacity basis from EIA.
- Bio-intermediate costs and refinery yields from SCR project experiments.
- ASTM finished fuel specifications are consistent with industry.
- Crude and product pricing data from OPIS by IHS Market.
- Fuel market projections from EIA, OPIS and ADOPT.
Process Model for Mild Hydrocracker Co-Processing

- Preliminary Aspen Plus & TEA models have been developed for single-stage fixed-bed mild hydrocracker

**Assumptions** in preliminary model
- One-stage HDC for bio-oil
- Similar yield as VGO HDC
- O removed via H$_2$O and CO$_2$
- No combination effects (either deleterious or synergistic)

**To be updated** in new model
- Yield
- Gas phase
- Combination effects
- Two-stage HDC for biocrude

- Detailed process model will be updated based on the coming co-processing experimental data
- Results from Aspen Plus model will be leveraged in the full refinery LP model
LP Model for Mild Hydrocracker Co-Processing

• Base-Delta Model in Refinery LP model

\[ y_i = y_i^{base} + \sum a_k (q_{f,k} - q_{f,k}^{base}) + \sum a_j (z_j - z_j^{base}) \]

Subject to \( q_{f,k}^L \leq q_{f,k} \leq q_{f,k}^U \), \( z_j^L \leq z_j \leq z_j^U \), \( f^L \leq f \leq f^U \)

\( y = \) yield, product quality; \( q_f = \) feedstock quality, \( z = \) operating condition, \( a = \) parameter \((\Delta y/\Delta q_f, \Delta y/\Delta z), f = \) capacity

• Base-Delta Model for Mild Hydrocracker

<table>
<thead>
<tr>
<th>( y )</th>
<th>( q_f )</th>
<th>( z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen consumption</td>
<td>Specific Gravity</td>
<td>Feed Rate</td>
</tr>
<tr>
<td>Product Yield</td>
<td>Sulfur, wt%</td>
<td>Conversion (%)</td>
</tr>
<tr>
<td>( \text{H}_2\text{S}, \text{CO}_2, \text{H}_2\text{O} ), Fuel Gas, C(_3), C(_4), Light Naphtha, Heavy Naphtha, Kerosene, Diesel, Unconverted Oil</td>
<td>50% ASTM Distillation</td>
<td>Recycle (% of fresh feed)</td>
</tr>
<tr>
<td>Product Qualities</td>
<td>Temp, °F</td>
<td>Catalyst Age (% used)</td>
</tr>
<tr>
<td>Required by downstream upgrading, or fuel blending (i.e. Cetane Index)</td>
<td>Basic Nitrogen, ppmv</td>
<td></td>
</tr>
<tr>
<td>Utility Consumption</td>
<td>( \text{Oxygen, wt}% )</td>
<td></td>
</tr>
</tbody>
</table>

**LP structure** has been modified in Aspen PIMS to adopt bio-oil/biocrude; Value of parameter \( a \) will be updated based on the coming experimental data and Aspen Plus model in Q3 & Q4
NREL is focused on developing full refinery optimization models with integrated co-processing of pyrolysis oil intermediates in the Fluid Catalytic Cracking unit.

Initially building models based on Petrobras-NREL CRADA project (Pinho et al, 2017) and prior Strategic Analysis / TC Platform Analysis work.

Model design methodology to enable quick incorporation of SCR project results.
FCC Co-Processing Analysis in FY2020

- Applied initial yield basis for FCC co-processing of pyrolysis oil from Petrobras-NREL CRADA.

- Improved yield model to allow user to assess pyrolysis oils of varying quality based on prior co-processing work in Strategic Analysis and TC Platform Analysis tasks.

  \[
  \text{FCC Product X Yield} = f(\text{oxygen content, } \% \text{ FP oil in FCC feed, FCC operating conditions})
  \]

- Leveraging refinery impact and co-processing work from (1) Co-Optima ASSERT and (2) TC Platform Analysis.
  - Refinery configuration and unit capacity basis per region.
  - Variable crude and product pricing structure from OPIS.
  - Finished product specifications from ASTM international.
  - Fuel market projections from EIA, OPIS and ADOPT model.
Preliminary FCC Co-Processing Analysis

- Develop understanding of the optimal co-processing strategy:
  - Reduce bio-intermediate MSP by avoiding Biorefinery upgrading capital and operating costs.
  - Determine bio-intermediate values to refineries through Aspen PIMS models.
  - Valuation of high-value co-products from catalytic pyrolysis processes.
Preliminary FCC Co-Processing Optimization

- Optimized scenarios have maximum delta between “Total Value” and “Total Cost”.
- Refinery analysis can help direct R&D.
- Preliminary insights:
  - Maximize yields.
  - Maximize co-product value.
  - Analysis can help optimize.

Preliminary example. Please do not cite or distribute.
Next Steps for SCR Co-Processing Analysis

• Experimental yield data
  - Develop statistical yield models
  - Incorporate yields into refinery LP models
  - Develop basis for process models
  - Derive basis for environmental analysis

Graphs from TCS 2016, Chapel Hill, NC, November 1, 2016
Next Steps for SCR Co-Processing Analysis

• Feed and product properties
  ➢ Empirical physical property models
  ➢ Product allocation analysis
  ➢ Blending and fuel quality analysis
  ➢ ASTM certification and spec development
  ➢ LCA / GHG analysis
  ➢ Inconsistencies in valuation / allocation

Example of insights developed from bio-oil physical property data.

Graphs from NREL TC Platform Analysis Q4 FY16 milestone
Downstream Refinery Impact Assessments

Assist in assessing co-processing topics outside of modeling scope:

- **Blendstock quality impacts** resulting from co-processing.
- **Bio-intermediate logistics** costs, challenges and constraints.
- **Operational reliability** impacts to downstream and ancillary unit operations:
  
  Managing low bio-oil thermal stability, managing immiscibility of bio-oils with refinery streams, acidity and corrosion potential, alkali and alkaline earth metals, unconverted oxygenated species, H₂O, CO and CO₂ in refinery light end / fuel gas streams, analysis methods for renewable allocations.

- **Potential benefits** to refiners from co-processing:
  
  Biofuels tax incentives, crude distillation capacity, FCC regenerator air blower capacity, FCC wet gas compressor, main fractionator flooding in FCC or Hydrocracker, reduced vanadium and nickel, low sulfur to sulfur plant and low nitrogen to sour water stripper.
Thank you!

Questions?

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