Techno-economic analysis for co-processing fast pyrolysis liquid in fossil refineries

NREL: Michael Talmadge, Christopher Kinchin, Helena Li Chum, Avantika Singh, Nick Carlson, Abhijit Dutta

Petrobras: Andrea de Rezende Pinho, Marlon BB de Almeida, Luiz Carlos Casavechia

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AUTHENTICATED U.S. GOVERNMENT INFORMATION GPO

Agenda

- Intro to NREL
- Overview of refinery analysis
- Results of NREL-Petrobras analysis
- New refinery analysis capabilities and applications
- Questions and discussion

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Techno-Economic, Sustainability, Market Analysis

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- Biomass Feedstocks
- Biochemical Process Development and Integration
- Biomass Deconstruction and Pretreatment
- Biogas Upgrading and Waste-to-Energy
- Biological and Catalytic Conversion of Sugars and Lignin
- Algal Biofuels
- Thermochemical Process Integration, Scale-Up, and Piloting
- Heterogeneous Catalysis for Thermochemical Conversion

Purpose of Refinery Analysis

- Leverage **global refining capacity** (220 billion-gal/year FCC) **to reduce cost of biofuels**.
- Apply an analysis approach to estimate the **value of bio-blendstocks and bio-oils**.
- Identify valuable properties and chemical co-products to **generate market pull** from refiners.
- Quantify **cost and environmental impacts** on refinery operations.

Techno-economic Analysis

Quantifies production cost for bio-blendstocks

Refinery Impact Analysis

Quantifies potential bio-product value to refiners

Break-Even Value (BEV) = f (Prices, Demands, Configurations, Properties, etc.)

Difference between BEV (including policy incentives) and minimum selling price (MSP) represents the potential benefits/value for refinery and supply chain.

History of NREL Refinery Analysis

2010 – 2014: National Advanced Biofuels Consortium

- Property comparisons of bio- and fossil- intermediates
- Initial biofuels blending model in Aspen PIMS

2014 – 2017: NREL-Petrobras Co-Processing Analysis

- Fluid Catalytic Cracking (FCC) and product finishing yield models coupled with economics for initial optimization capabilities.

2016 – 2021: Co-Optima Refinery Analysis (collaboration with PNNL and ANL)

- Complete refinery models with various configurations quantify values of bio-blendstocks and bio-intermediates.
- Tools integrated with Aspen Plus quantify environmental benefits.
- Refinery models are now capable of direct blending bio-blendstocks and co-processing bio-intermediates via hydroprocessing and FCC.

PNNL = Pacific Northwest National Lab and ANL = Argonne National Lab.

NREL-Petrobras FCC Co-Processing Analysis

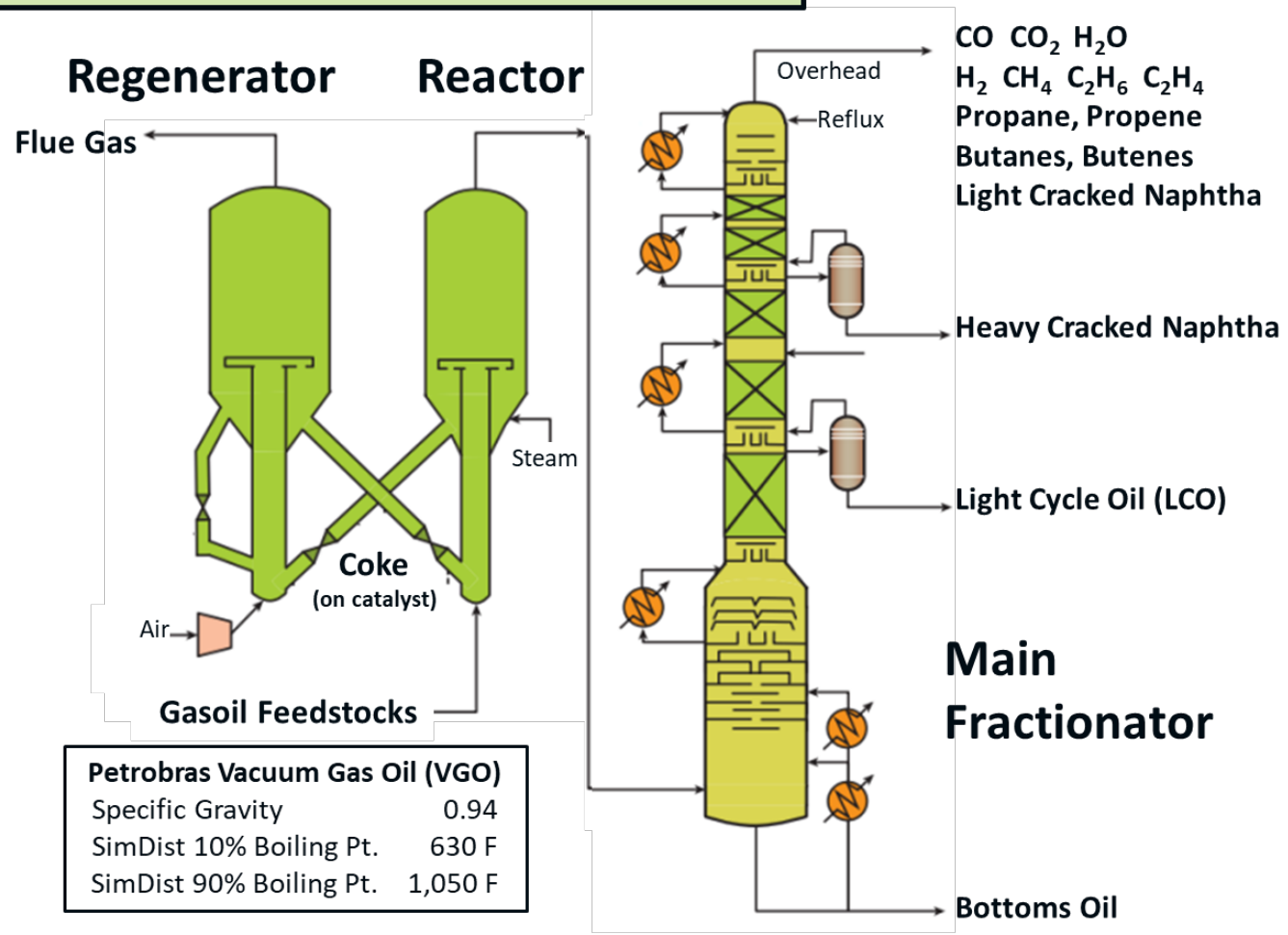
Assess the technical and economic feasibility of co-processing raw, biomass-derived pyrolysis oil with fossil feedstocks in FCC to produce renewable hydrocarbon fuels and chemicals.

Leverage existing FCC capacity to reduce economic risk of biofuels production.

- 90-billion gallons/year in US
- 220-billion gallons/year globally

PFD Source: CEP, May 2014

FCC Conversion = 100 – LCO – Bottoms



Petrobras Vacuum Gas Oil (VGO)	
Specific Gravity	0.94
SimDist 10% Boiling Pt.	630 F
SimDist 90% Boiling Pt.	1,050 F

Petrobras FCC Co-Processing Experiments

Petrobras "SIX" demo unit has same hardware as a commercial FCC

- Feed nozzles
- Riser cyclone
- Packed stripper
- Heat balanced
- Mass flowrate: 200 kg/h
- Riser: L=18 m

Co-Processing Experiments

- Two pine-derived pyrolysis oils with consistent physical properties
- Mass balance range of 96 – 100%
- 3-hour test runs
- Cumulative time w/ py-oil > 400 hours
- Up to 20 wt% pyrolysis oil in FCC feed
- 54 experimental data points

Fuel Processing Technology 131 (2015) 159-166

Co-processing raw bio-oil and gasoil in an FCC Unit

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Fuel 188 (2017) 462-473

Fast pyrolysis oil from pinewood chips co-processing with vacuum gas oil in an FCC unit for second generation fuel production

Andrea de Rezende Pinho [a,*], Marlon B.B. de Almeida [a], Fabio Leal Mendes [a], Luiz Carlos Casavechia [b], Michael S. Talmadge [c], Christopher M. Kinchin [c], Helena L. Chum [c]

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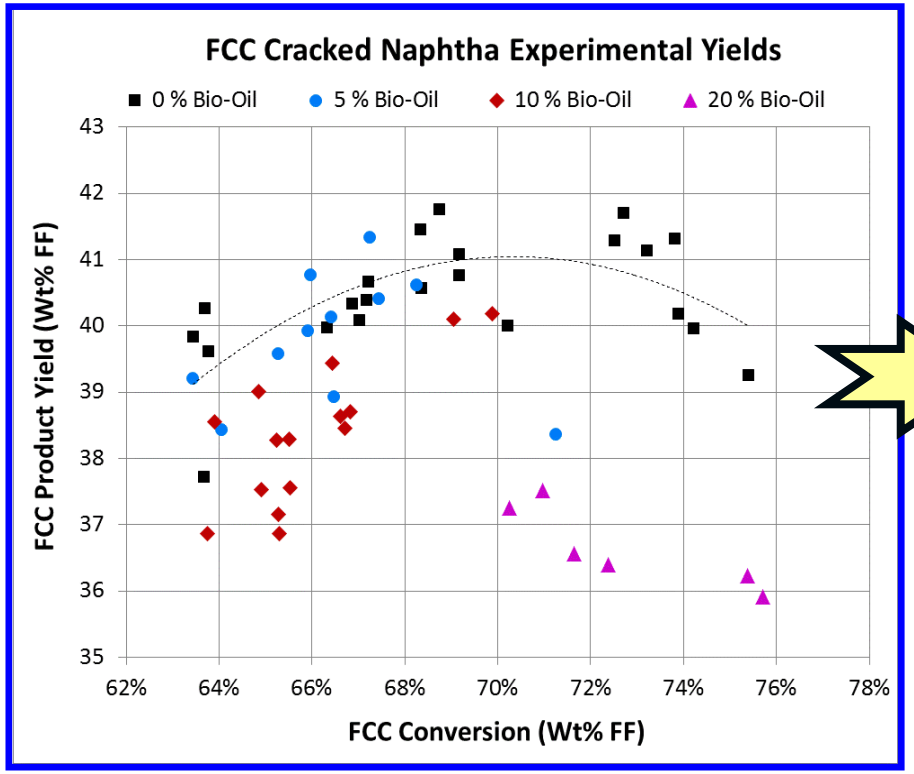
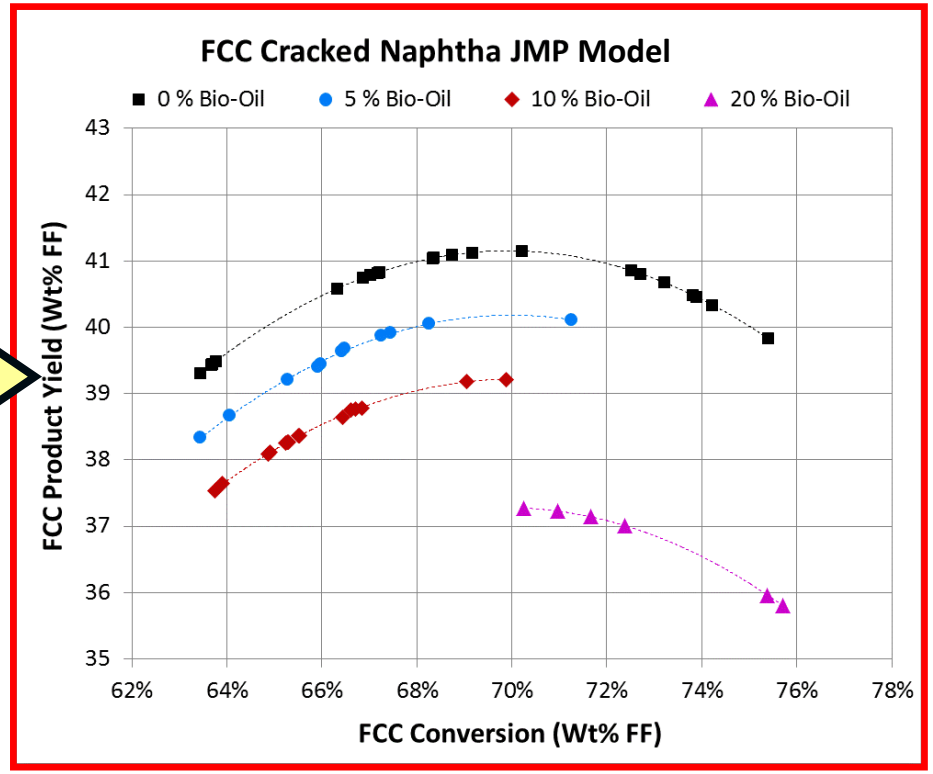
NREL-Petrobras Yield Model from Experimental Data

- Utilized statistical software package to derive yield models from experimental data.
- Yield models, combined with economics, enable optimizations to identify most profitable operating points.



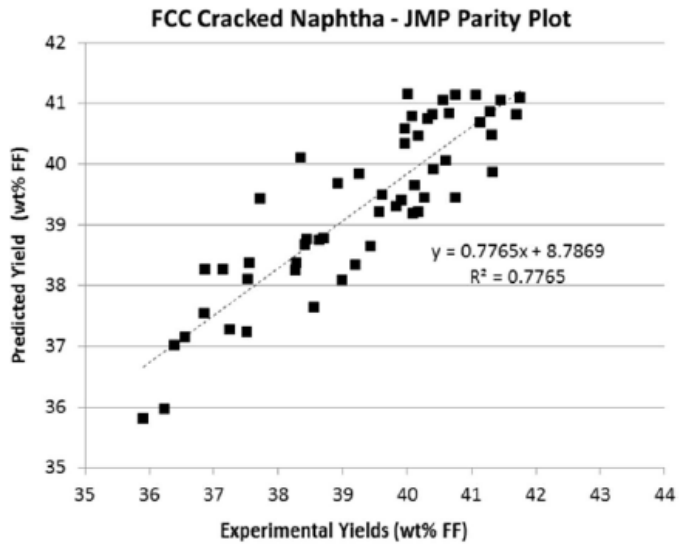


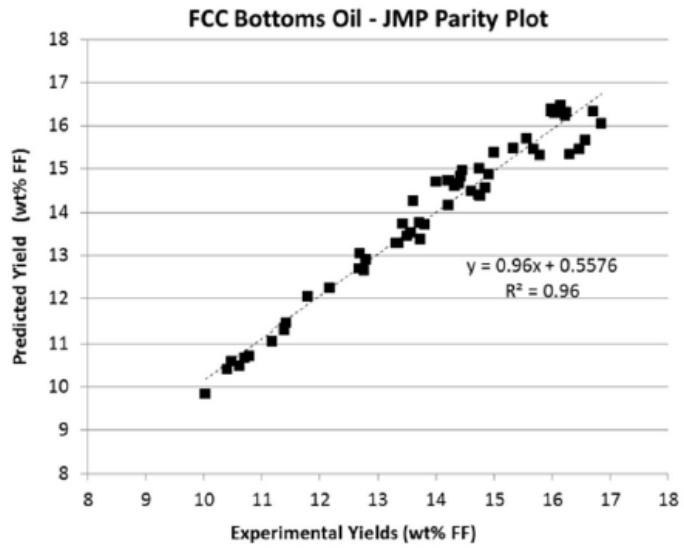
Complete FCC Yield Model

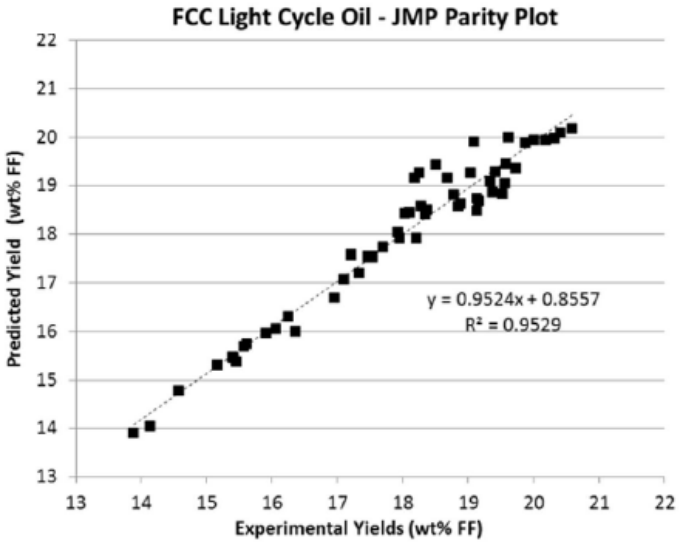
Oxygen Species	Refinery Fuels	LPG Products	Liquid Products
CO CO_2 Water	Dry Gas (C_2-)	Propane Propylene	Cracked Naphtha
	Coke	i-Butane n-Butane	Light Cycle Oil (LCO)
		Butenes	Bottoms Fuel Oil

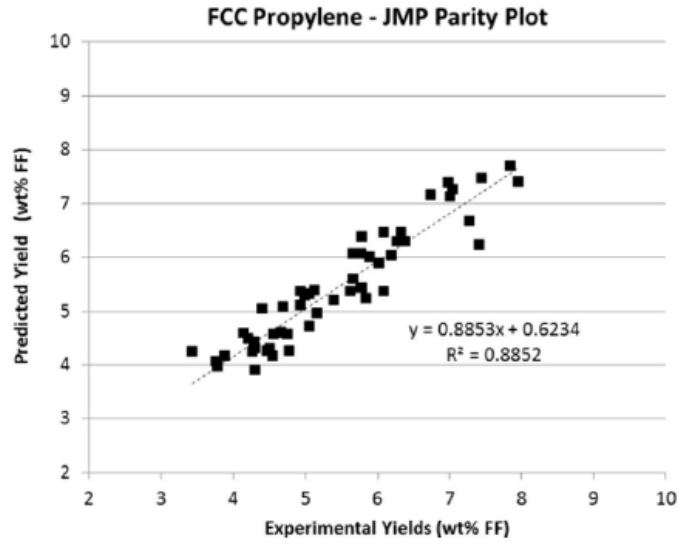
Yield Model Validations with Experimental Data

- Validated yield model predictions for all raw products from FCC unit.
- Utilized Aspen HYSYS model to further validate model predictions as a function of FCC reactor severity.



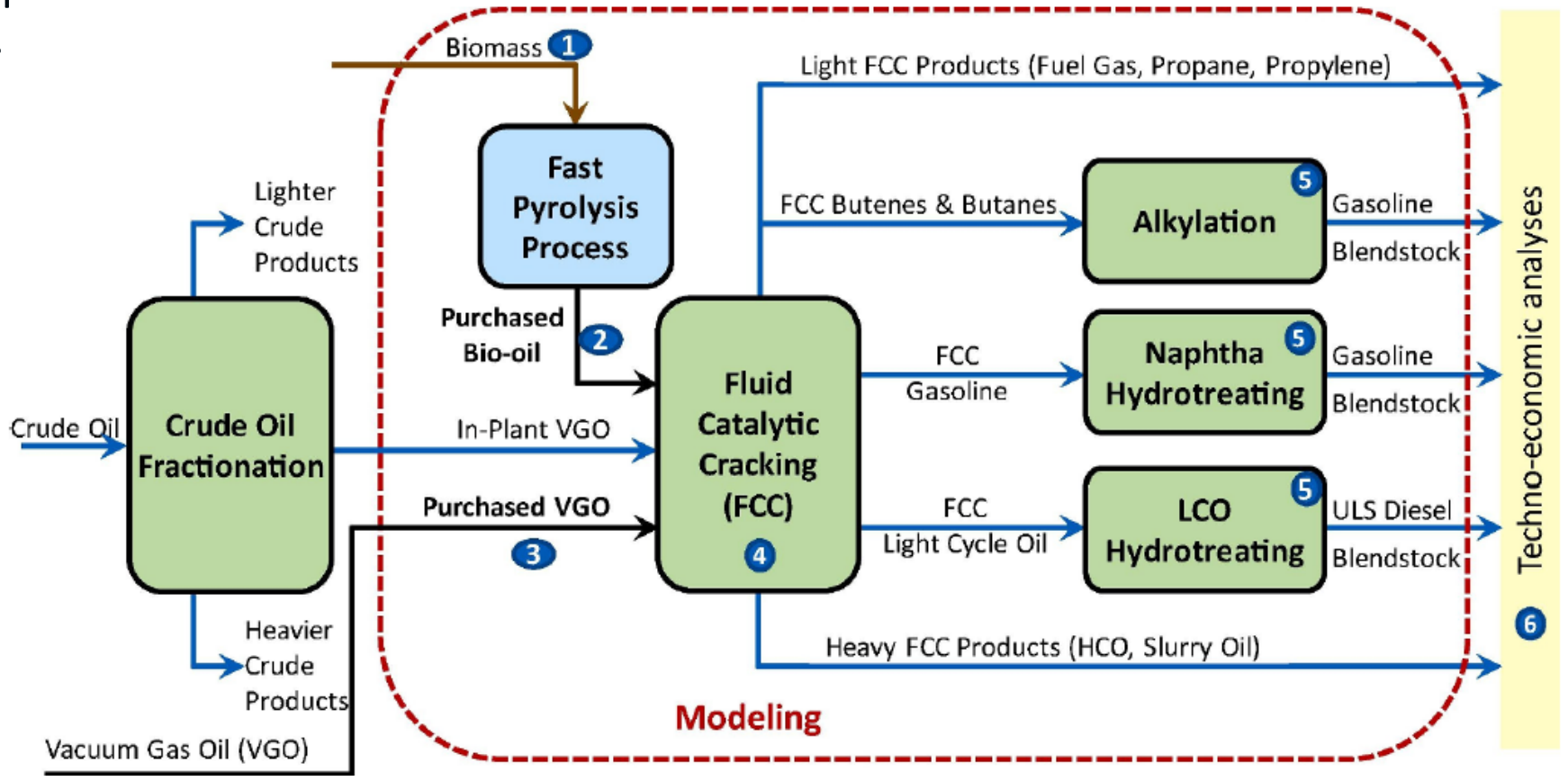






Scope of NREL-Petrobras Analysis

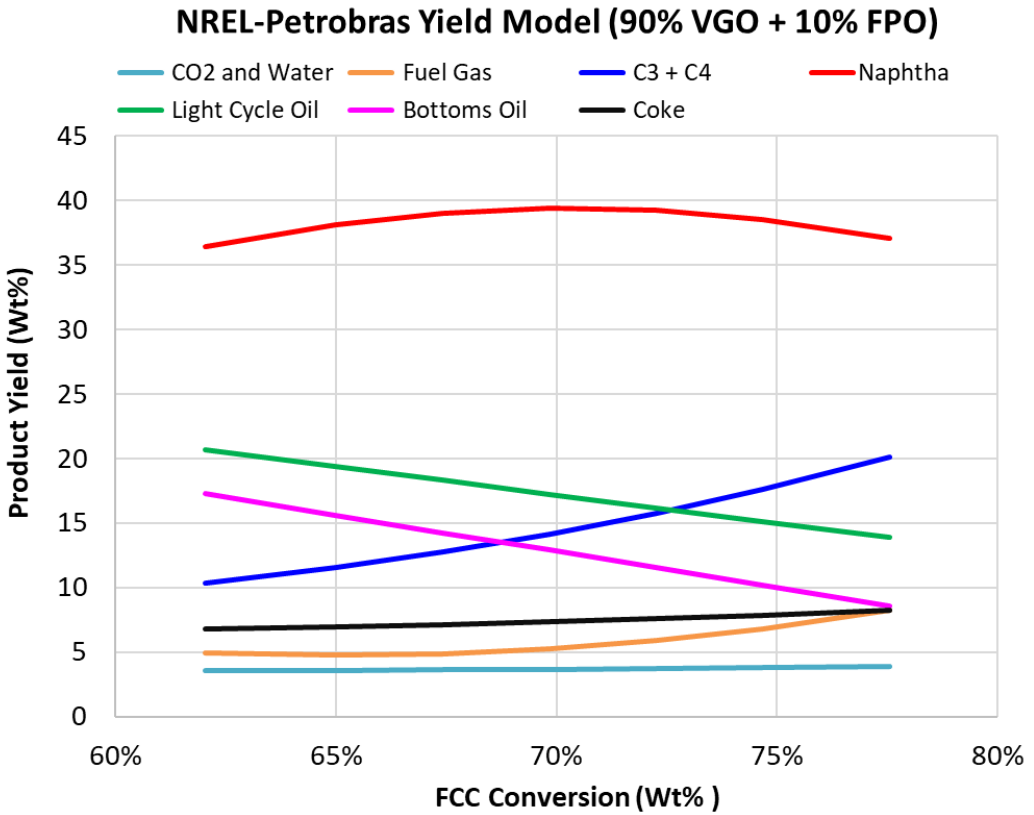
- Scope includes downstream product upgrading units for finished blendstocks:
  - i-C_4 and C_4-olefins converted to high-octane gasoline blendstock via **alkylation**.
  - **Cracked naphtha hydrotreating** to gasoline blendstock.
  - **LCO hydrotreating** to ULSD blendstock.



Enabling Optimization with Yield and Pricing Models

- Add product pricing model to convert complex FCC yields to single value ($/unit FCC feed)
- Profit = value of products minus
  - Cost of feeds
  - Costs of catalysts, utilities, H_2, royalties
  - Amortized capex

Refinery Process Yield Model + Variable Pricing Model

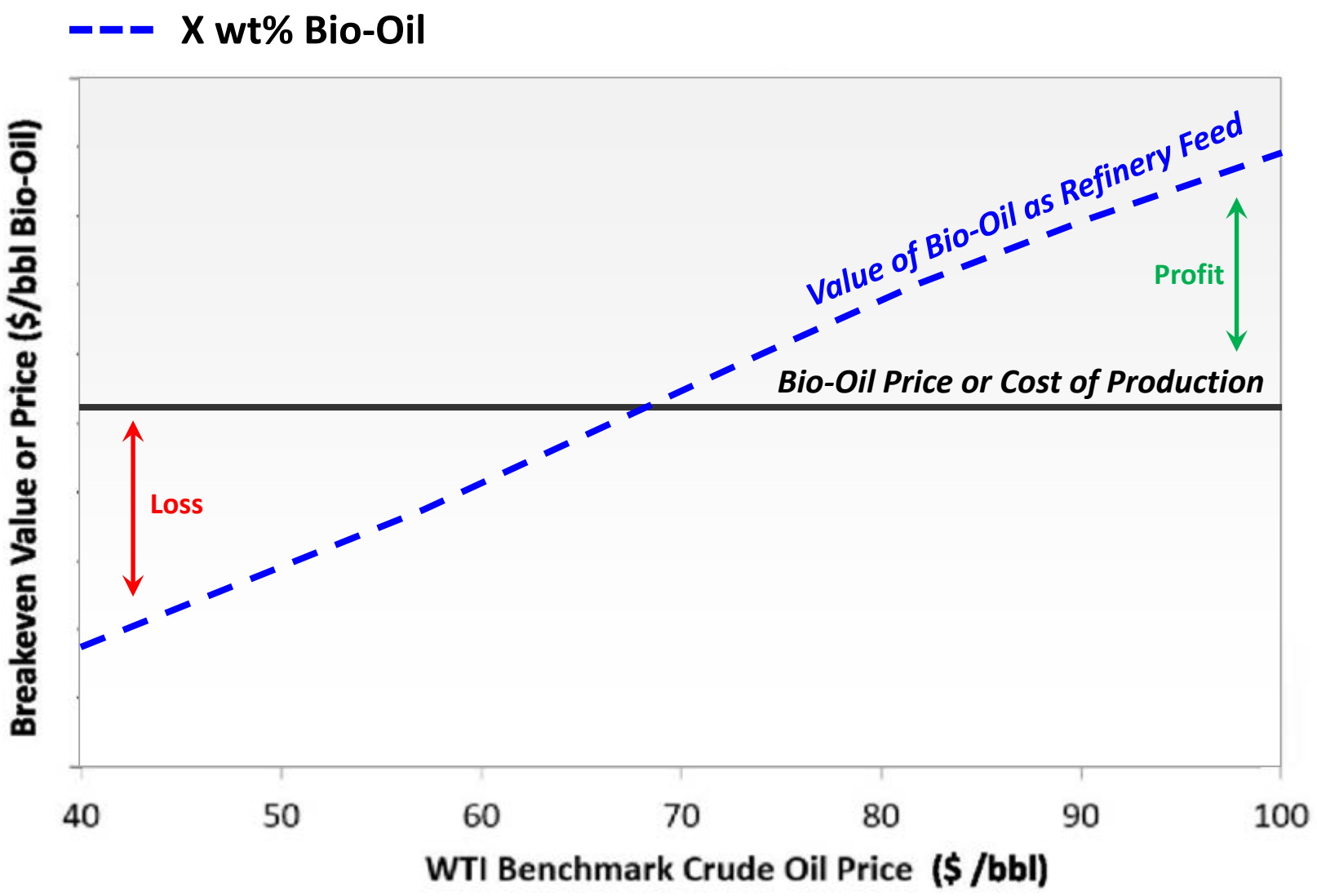


West Texas Intermediate (WTI) 80 ($/BBL)

Products	Price	Unit
Natural Gas	0.1195	$/LB
Propane	0.9979	$/GAL
Propylene	2.2232	$/GAL
n-Butane	1.2233	$/GAL
i-Butane	1.2998	$/GAL
Conventional Regular Gasoline	2.2661	$/GAL
Conventional Midgrade Gasoline	2.3501	$/GAL
Conventional Premium Gasoline	2.5619	
Reformulated Regular Gasoline	2.3669	$/GAL
Reformulated Midgrade Gasoline	2.5061	$/GAL
Reformulated Premium Gasoline	4.0000	$/GAL
Alkylate Intermediate	2.5617	$/GAL
Jet Fuel	2.4149	$/GAL
Ultra Low Diesel Fuel (ULSD)	2.4193	$/GAL
California Diesel Fuel (CDF)	2.0000	$/GAL
Heating (No 2) Oil	2.3891	$/GAL
Light Cycle Oil (LCO)	2.3916	$/GAL
Vacuum Gas Oil (VGO)	2.2587	$/GAL
Residual (No 6) Oil - 0.3% Sulfur	1.3910	$/GAL
Residual (No 6) Oil - 1% Sulfur	1.0540	$/GAL
Residual (No 6) Oil - 3% Sulfur	0.7574	$/GAL

Illustrative Example for Presentation of Results

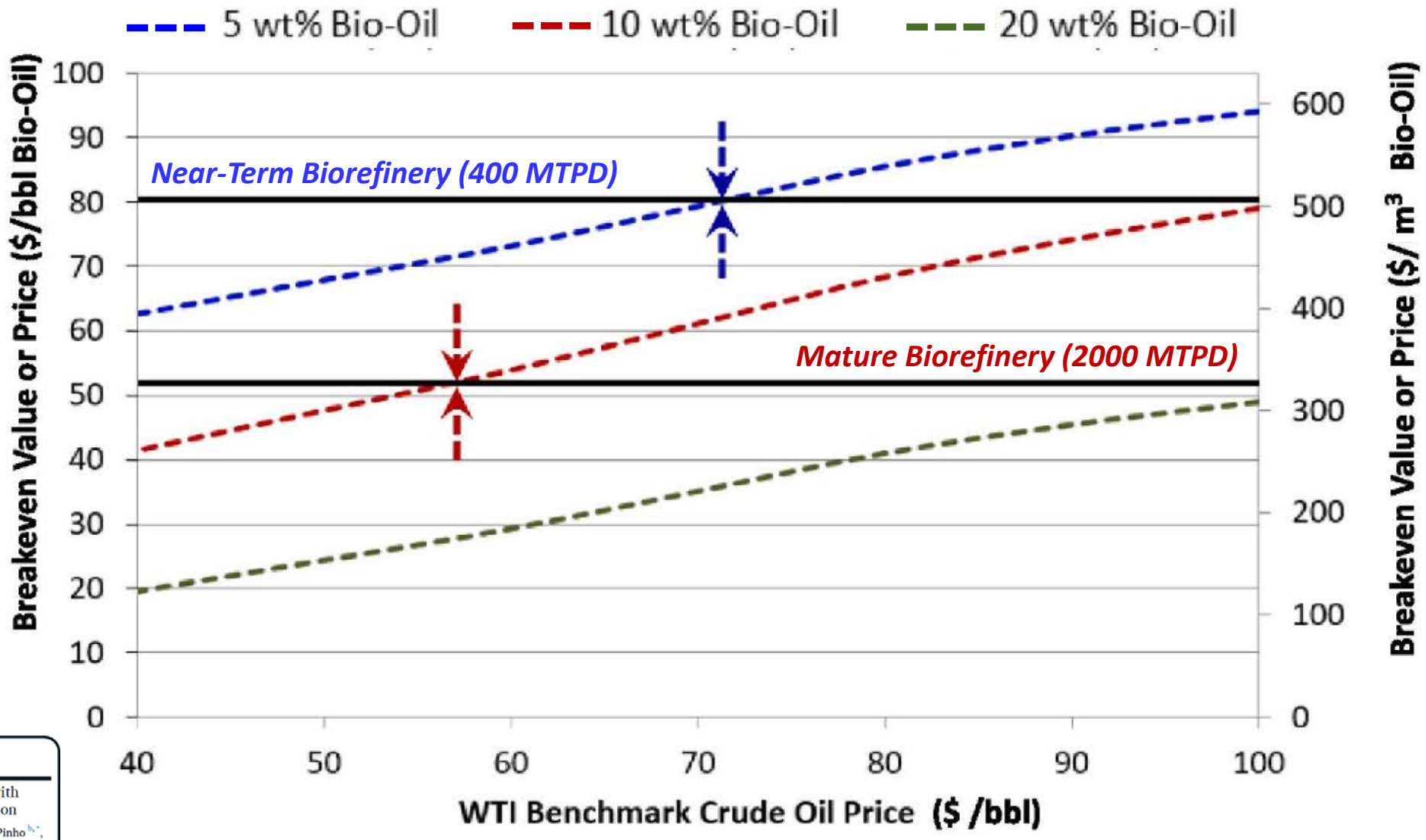
- Dark, solid lines represent costs of bio-oil production at different biorefinery scales.
- Colorful, dotted lines represent the values of bio-oil as refinery (FCC) feedstock.



Breakeven Value for Fast Pyrolysis Oil Co-Processing

Breakeven Analysis

- Revenue equals cost at “Breakeven Point”
- “Pyrolysis Oil Breakeven Value” = f(value of products)
- Profit realized when cost < “Breakeven Value”



Fuel 293 (2021) 119960

Techno-economic analysis for co-processing fast pyrolysis liquid with vacuum gasoil in FCC units for second-generation biofuel production

Michael Talmadge [a,*], Christopher Kinchin [a], Helena Li Chum [a], Andrea de Rezende Pinho [b,*], Mary Biddy [a], Marlon B.B. de Almeida [b], Luiz Carlos Casavechia [c]

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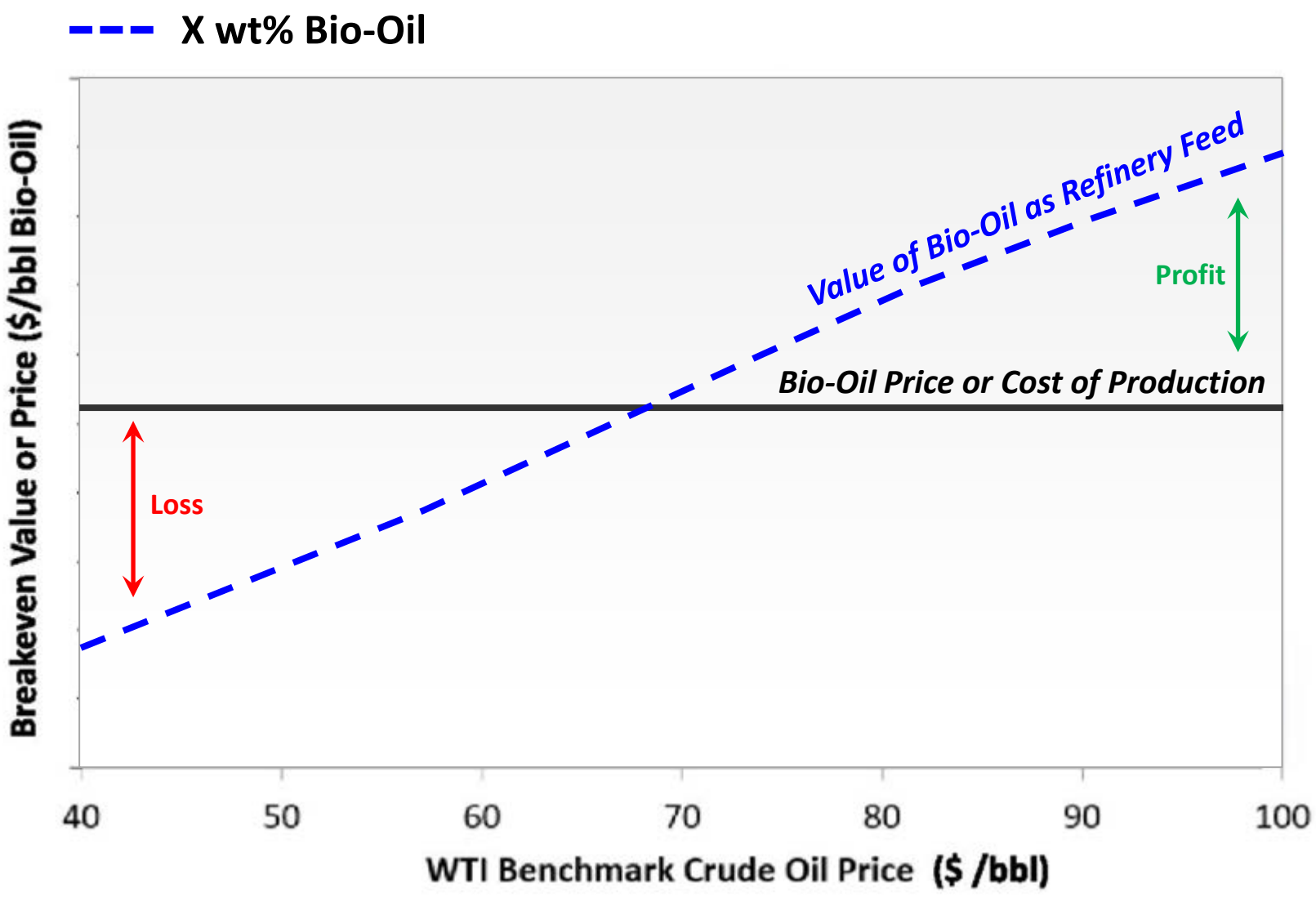
[b] PETROBRAS, Centro de Pesquisas e Desenvolvimento Leopoldo A. Miguez de Mello (CENPES), Ilha do Fundão, Av. Horácio Macedo, 950, Rio de Janeiro, RJ, Brazil
[c] PETROBRAS-SIX, Rodovia do Xisto BR 476, km 143, São Mateus do Sul, PR, Brazil

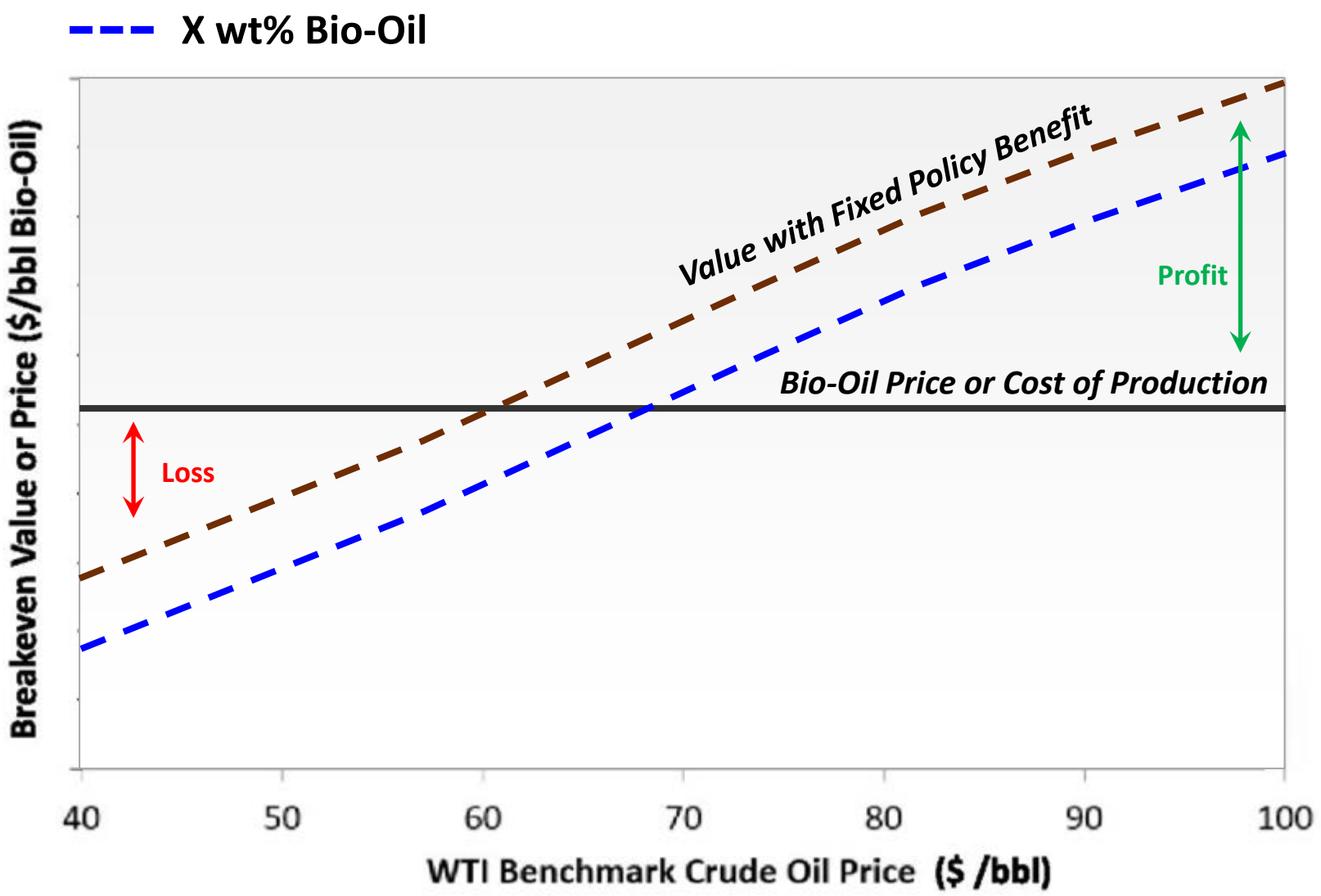
Policy Insights with Illustrative Example

- Biomass and derivative prices are NOT tied to crude prices.
- Refineries have high level of risk due to uncertainty in product market prices.
- Future tech development will increase value and decrease cost.
- Refiners need policy help in near-term when market values are low.



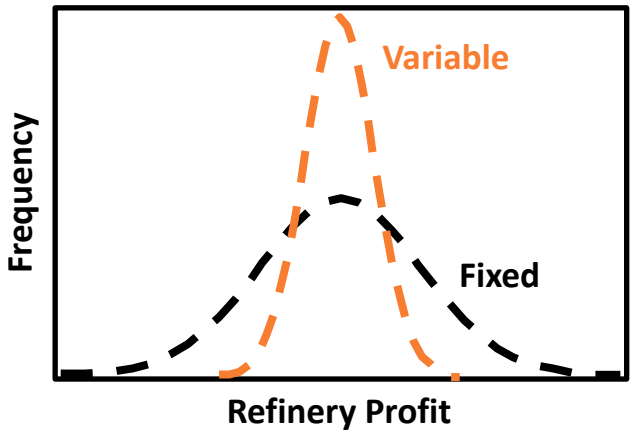
Policy Insights with Illustrative Example

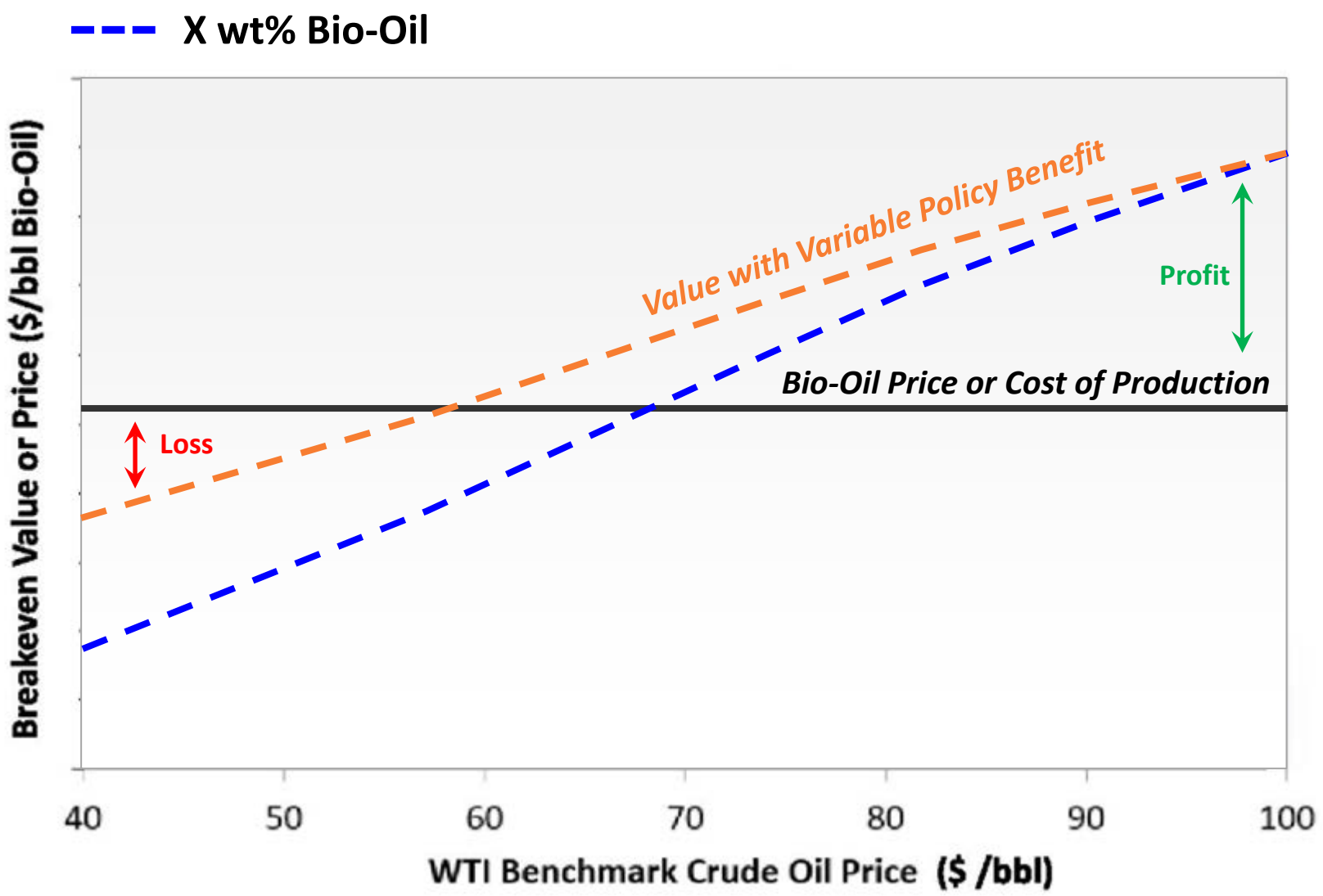
- Fixed-value policy may be relatively costly for tax-payer/consumer.
- Risk of economic loss may remain substantial.



Policy Insights with Illustrative Example

- Variable policy may reduce risk of economic loss while minimizing excessive profit.
- Modeled results show impact on risk probability.





Overview of Refinery Analysis with Aspen PIMS

Refinery configuration and unit capacity basis from EIA.

Bio-blendstock/-intermediate cost, props, yields from TEA.

ASTM fuel specifications consistent with industry.

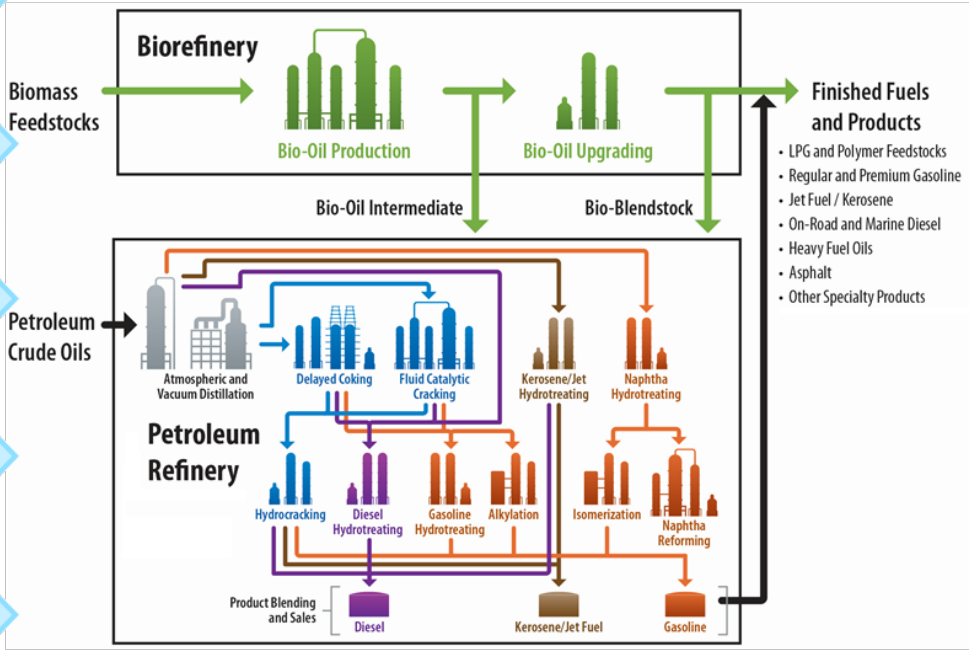
Crude and product pricing data from OPIS and PRISM.

Market projections from EIA, OPIS, ADOPT.

Refinery capital investment basis from published sources.

Direct industry input through several on-going projects.

Biorefinery Models



Refinery Models in Aspen PIMS By AspenTech

Integrated with LCA calculations.

Bioeconomy Optimizations.

R&D needs via data gaps.

Outputs:

- Complete operational and economic profiles for optimized refinery solutions.
- Valuations of bio-feedstocks.
- Effective policy designs to de-risk biofuels production in refineries.
- Basis for US refinery network of “meta-models” for bioeconomy modeling.

Davison Circulating Riser (DCR) for Co-Processing

Evaluate FCC co-processing strategies by feeding CFP oils or other biogenic materials (FOGs, waxes) with VGO into the riser to produce BC-containing fuels

Key System Specifications – DCR for Co-processing

Feed Type: Liquids

Feed Rate: 1.2 kg/hr

Catalyst Type and Form Factor/Size: Refinery-type, zeolite-based, fluidizable (FCC), 80-100 micron.

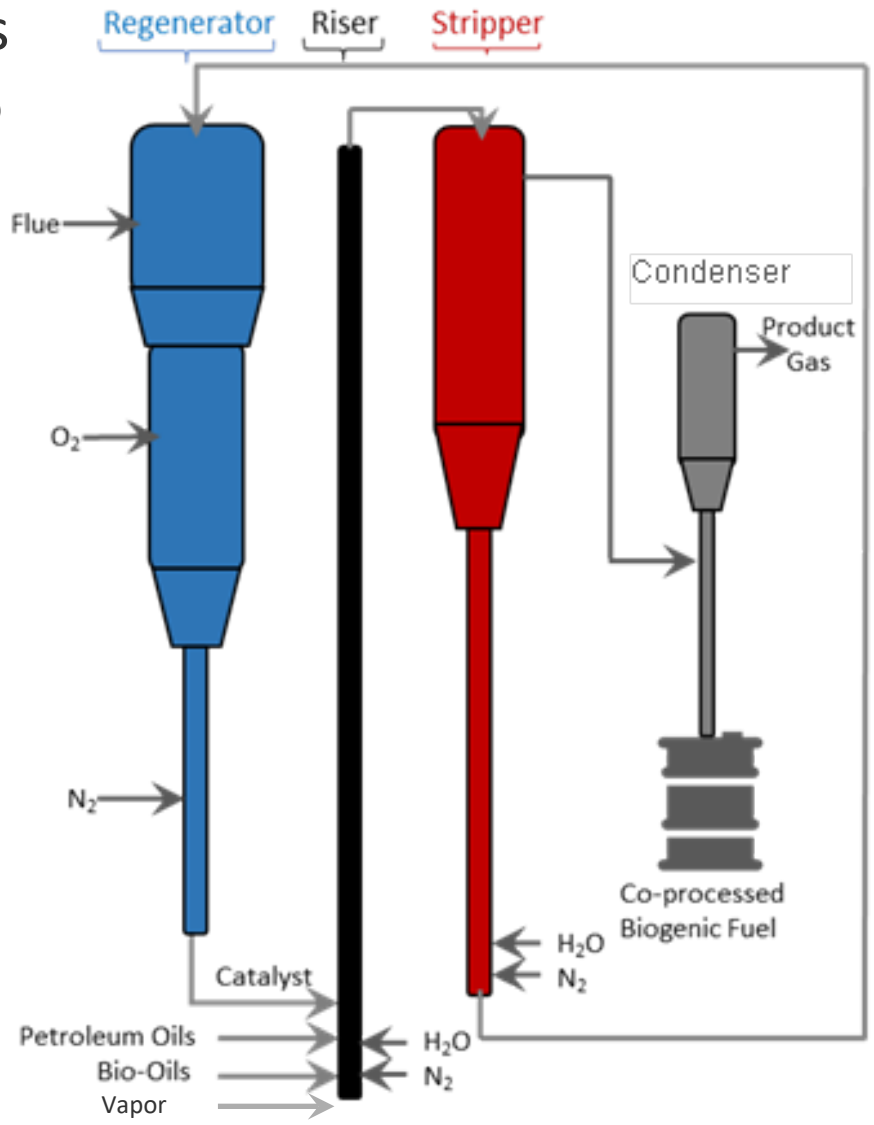
Catalyst Charge/Feed Rate: 1.8 kg, circulation rate 7-10 kg/hr

Operating Temperature Range: 475-550°C

Operating Pressure Range: 2-2.6 bar

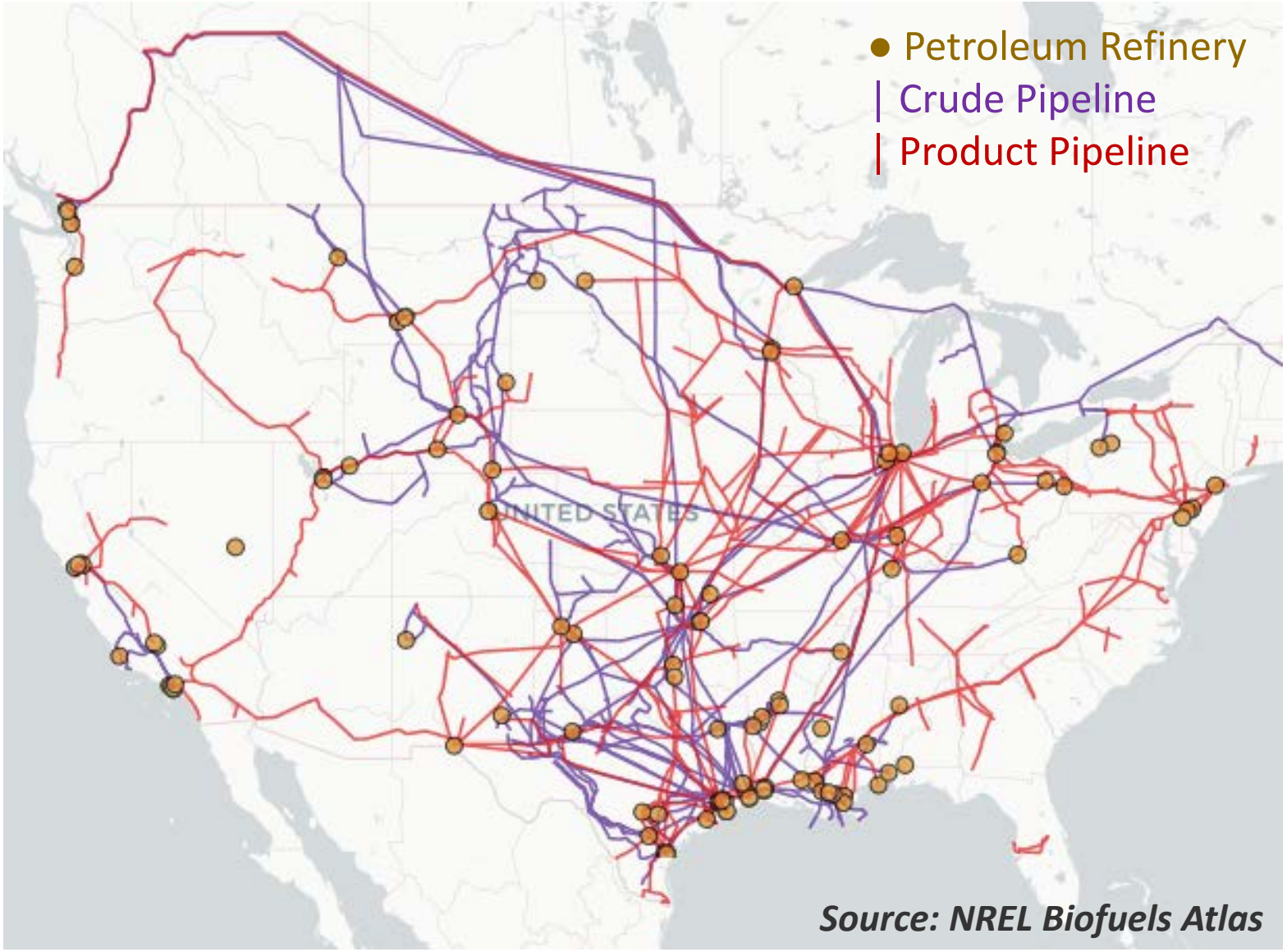
Reactor Configuration(s): Riser reactor + stripper + regenerator

Additional Specifications: Catalyst recirculated for stripping (HC removal) and regeneration (coke removal). DCR mimics FCC refinery operations by cracking large molecules to fuel-range molecules.



Future Goals for Refinery Analysis

- Identify low-carbon and low-cost strategies for renewable fuels and chemicals that leverage existing refineries.
- Continue to collaborate with industry partners on commercializing attractive business cases.
- Inform effective policy designs with modeled results.



Developing New Modeling Capabilities

- Integrate **emerging technologies** (and feedstocks) for bio-oil production
  - Catalytic fast pyrolysis
  - Hydropyrolysis
  - Hydrothermal liquefaction
- Develop analysis for **renewable olefins and aromatics** from refineries
- Integrate **environmental calculations** for multi-objective optimizations (ANL)
- Explore **alternative integration points**
  - Hydroprocessing (PNNL/NREL)
  - Residuum Fluid Cat Cracking (RFCC)
  - Delayed Coker
  - Fluid/Flexi-Coker
  - Marine Fuels
- Utilize refinery models in **bioeconomy resource optimizations**

PNNL = Pacific Northwest National Lab and ANL = Argonne National Lab.

Source Publications

- Pinho, Andrea de Rezende, Marlon B.B. de Almeida, Fabio Leal Mendes, Luiz Carlos Casavechia, Michael S. Talmadge, Christopher M. Kinchin, and Helena L. Chum. 2017. “Fast Pyrolysis Oil from Pinewood Chips Co-Processing with Vacuum Gas Oil in an FCC Unit for Second Generation Fuel Production.” Fuel 188 (January): 462–73. https://doi.org/10.1016/j.fuel.2016.10.032.
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- Talmadge, M., H. Chum, C. Kinchin, Y. Zhang, M. Biddy, A. de Rezende Pinho, M. B. B. de Almeida, F. L. Mendes, L. C. Casavechia, and B. Freel. "Analysis for co-processing fast pyrolysis oil with VGO in FCC units for second generation fuel production." TCS—Symposium on Thermal and Catalytic Sciences for Biofuels and Biobased Products, Chapel Hill, NC. 2016.

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ANL

Hao Cai
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Questions?

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