FAA CENTER OF EXCELLENCE FOR ALTERNATIVE JET FUELS & ENVIRONMENT

Alternative Jet Fuel Supply Chain Analysis

ASCENT 1

Conversion Pathways to Alternative Fuels

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Lead investigators: M. Wolcott, M. Garcia-Perez, X Zhang

Bi-Annual Meeting

[13 October 2015]

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AVIATION SUSTAINABILITY CENTER

Agenda

- Task/Subtask Overview
- Summary of Progress
- Summary of Key Accomplishments
- Next Steps
- Questions and Answers

Task/Subtask Overview

Technical Problem Addressed:

Up to now all the jet fuel supply chain analyses published have been limited to **standalone jet fuel technologies without bio-products**. The potential techno-economic and environmental benefits of **using existing industrial infrastructure** and **the production of co-products** on jet fuel production scenarios could facilitate the deployment of alternative jet fuel supply chains.

Our main long term contribution:

Design cases of: **(1)** standalone AJF production technologies, **(2)** bio-refineries that take advantage of existing industrial infrastructure and **(3)** bio-refineries generating co-products from AJF intermediates.

The **use of these design cases in the analysis of regional supply chains**.

Task/Subtask Overview

What are we doing?

Creating a "database" with **design cases** of Conversion Technologies for the production of Alternative Jet Fuels (AJFs).

Using the information in the data base to **identify potential synergy** between AJF production technologies and existing infrastructure (Pulp and Paper mills, Sugarcane Mills, Corn ethanol, Petroleum Refineries). Creation of Bio-refinery concepts.

Using this data base of "Design Cases" to **identify intermediate streams and potential routes to generate value added products**.

Using the information in the data base to **conduct a techno-economic analysis** of alternatives to **produce aviation fuels in a given region as part of a supply chain**.

Identifying technical gaps towards commercialization of AJF processes (**Evaluation of Technology Readiness Level**).

Task/Subtask Overview

Technologies Relevant to the Goals of the Project:

Technologies Approved by ASTM:

- Hydroprocessed ester and Fatty Acid (HEFA)
- Fischer Tropsch (FT)
- **Amyris Direct Sugars to Hydrocarbons (DSHC)**

Technology Studied in this Project

Jet Fuel Production Technologies under study:

- **Gevo Alcohol to Jet (ATJ)**
- **Hydrotreated Depolymerized Cellulosic Jet (HDCJ)**
- **Synthetic Kerosene and Synthetic Aromatic Kerosene**
- **Catalytic Hydrothermolysis (CH)**
- **Synthesized Kerosene-containing Aromatics (FT-SKA)**

Technologies Studied in this Project

Existing Infrastructure that can be leveraged to produce Jet Fuel:

- **Petroleum Refineries**
- **Pulp and Paper Mills**
- **Sugar Cane Mills**
- **Corn Ethanol Mills**

Technologies Studied in this Project

Summary of Progress

Alternative Jet Fuel Technologies

Design Case 1: Virent Synthetic Kerosene and Synthetic Aromatic Kerosene (SK&SAK) (Tanzil Abid Hossain)

Design Case 2: ARA Catalytic Hydrothermolysis (CH) (Mond Guo and Senthil Subramaniam, Xiao Zhang)

Design Case 3: Synthesized Kerosene containing Aromatics (FT-SKA) (Senthil Subramaniam, Alex Dunsmoor, Kirstin Egerton, Lara Heersema, Chris Huff)

Design Case 4: Direct Sugars to Hydrocarbons (DSHC) (Carlos Alvarez-Vasco, Joe Evans, Roger Kim, Lindsey Malkames, Matt Tyler, Jenny Voss, Xiao Zhang)

Design Case 5: Alcohol to Jet (ATJ) (Scott Geleynse, Alex Hadera, Luda Ledsukin, Armin Mehinagic, Serah Njau, Xiao Zhang)

Design Case 6: Hydrotreated Depolymerized cellulosic Jet (HDCJ) (Manuel Garcia-Perez)

Technologies in Existing Infrastructure

Design Case 7: Dry Milling (Corn-Ethanol) (Tanzil Abid Hossain)

Design Case 8: Sugar Cane Mills (Jonathan Pulgarin-Leon)

Design Case 9: Pulp and Paper (Senthil Subramaniam, Ameen Alali, Brady Seroshek, David Fugiel, Leon Li, Min Zheng)

Design Case 10: Petroleum Refineries (Jonathan Pulgarin-Leon, Mohammad Abdulelah, Ali Alramadhan, Shawn Elder, Parker Scott)

First reports of all 10 design cases have been completed and reviewed by technical experts

Summary of Progress

Alternative Jet Fuel Technologies

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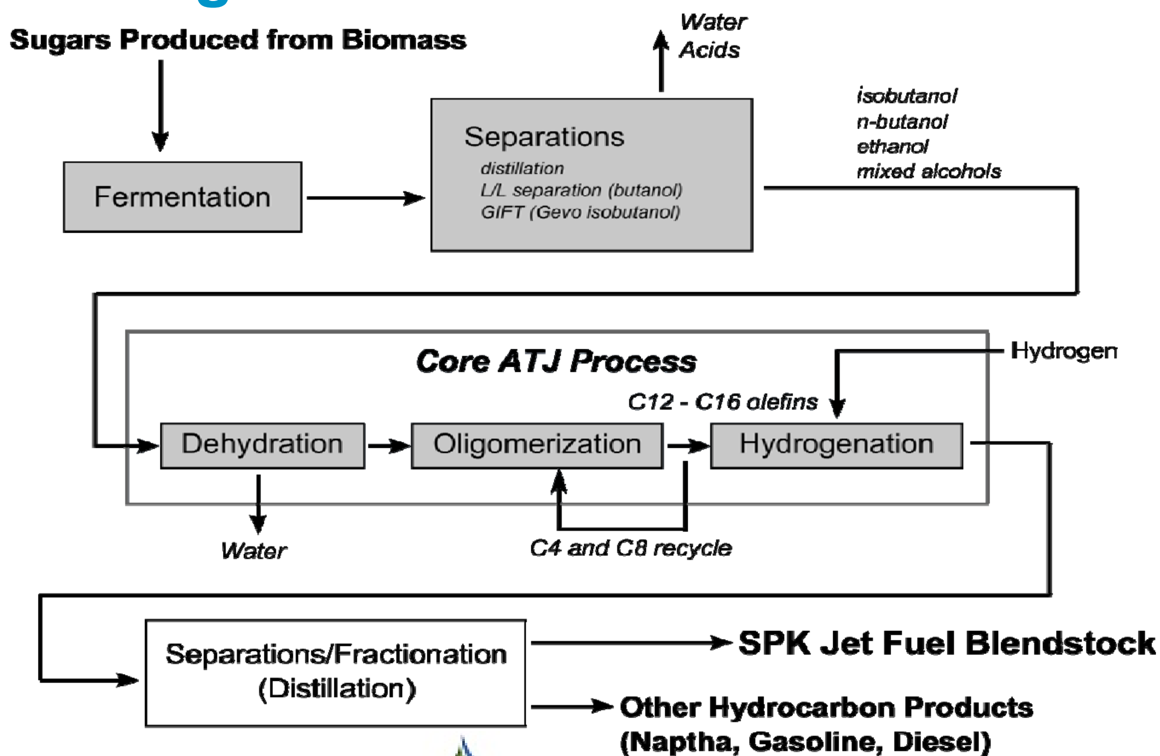
Alcohol-to-Jet (ATJ)

The ATJ pathway upgrades alcohols to fuels using fairly well-established catalytic technologies.

Isobutanol, n-butanol, ethanol, and mixed alcohol platforms are all explored.

ATJ boasts potential implementation with existing alcohol plants.



gevo

- •Fermentation of isubutanol using proprietary modified organism
- •Gevo Integrated Fermentation Technology (GIFT Process) provides continuous removal of alcohol during fermentation

Cobalt — BUILDING A SUSTAINABLE FUTURE

- •n-butanol based platform for fuel and a variety of other chemicals
- •Proprietary pretreatment and fermentation process

BYOGY RENEWABLES

- •Flexible technology aimed to convert a variety of alcohols, including ethanol
- •Currently developing facilities in South America

LanzaTech

- •Gas fermentation. Uses carbon monoxide as a feedstock.
- •Currently developing conversion technology to process emissions from steel mills

Summary of Progress

Alternative Jet Fuel Technologies

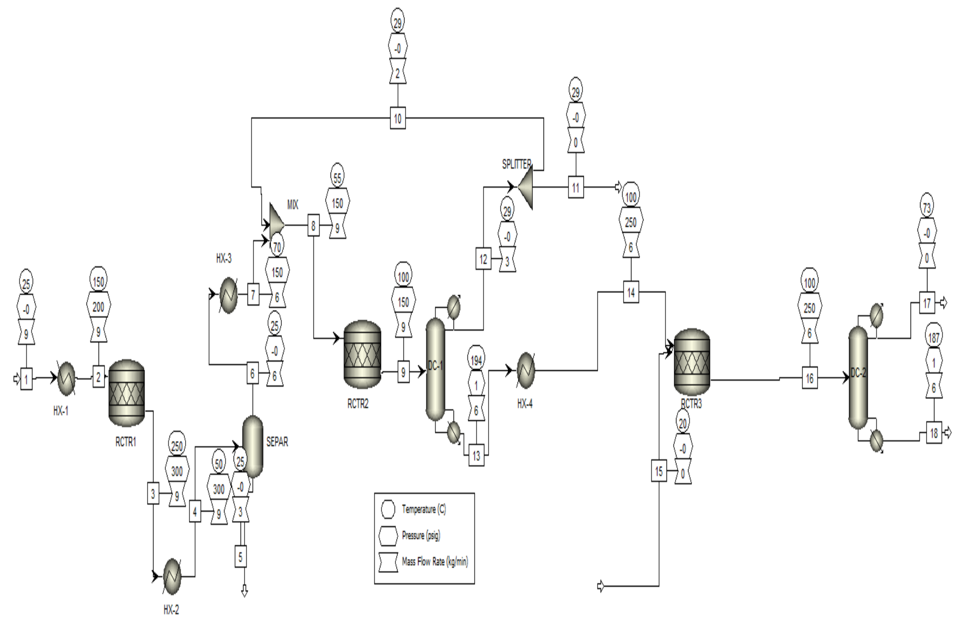
Alcohol-to-Jet (ATJ)

Feedstock: 9.26 kg/min (isobutanol)

Specifications	Dehydration Reactor	Oligomerization Reactor	Hydrogenation Reactor
Temperature (°C)	250	100	100
Pressure (psig)	300	150	250
Conversion (%)	90	90	99
Catalyst	Gamma-Alumina	Amberlyst-35	Nickel

Reactor	Diameter (ft)	Height (ft)	Volume (cubic ft)
Dehydration	1.8	8.9	22.6
Oligomerization	1.8	8.9	22.6
Hydrogenation	3.0	10.0	70.6

ASPEN MODEL



Capital Cost and Catalysts

Reaction	Reactor Volume (cubic ft)	Reactor Purchase and Installment (US $)	Required Catalyst Per Year (kg)	Cost of Catalyst Per Year (US $)
Dehydration	22.6	58,300.00	14,924	13,851
Oligomerization	22.6	58,300.00	2,287	7,578
Dehydration	70.6	107,000.00	2,794	129,834
	Total	$223,600	Total	$151,263

Feeds and Products	Current Cost	Flowrate (kg/min)	Total Annual Price ($)
Isobutanol In	$0.60/gal	9.26	6,390,000
Hydrogen In	$10/1000 SCF	0.08	165,200
Jet Fuel Out	$3.62/gal	6.17	5,110,000

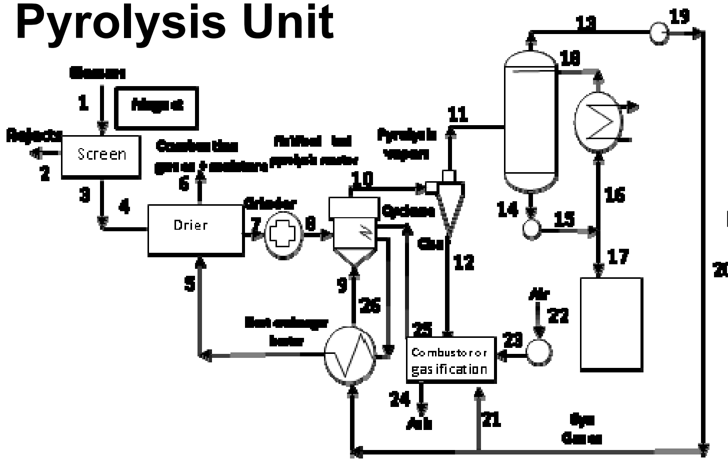
*Data presented are based on pilot scale simulation not verified by industrial operation.

Summary of Progress

Alternative Jet Fuel Technologies

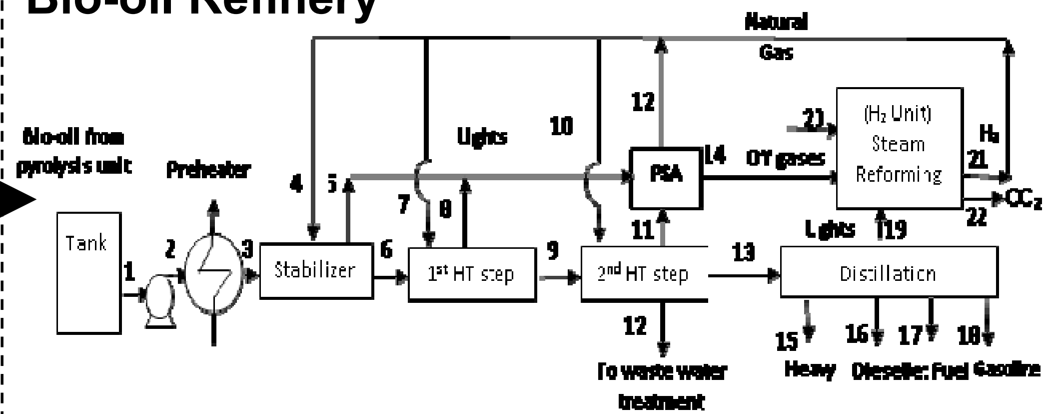
Pyrolysis Technology

Pyrolysis Unit



Bio-oil

Bio-oil Refinery[1]



Number of Pyrolysis Units: 4, Capacity per unit: 500 dry t/day

Feedstock: Pine, Moisture Content: 50 wt. %,Chips size: 14 mm

Technology: Fluidized Bed with Bio-char combustion

Biomass Rejected: 10 dry t/day: Biomass Pyrolyzed: 490 dry t/day

Heat transferred in the pyrolysis reactor: 11.7 MW

Heat needed to heat the carrier gas: 16.2 MW

Heat consumed in the drier: 5.6 MW

Yield of oil: 64 wt. %

Bio-oil produced: 345.6 t/day (water content: 26.5 wt. %)

Bio-oil produced: 76,095 gal/day

CO2 released: 412.2 tons/day

Bio-oil Processing capacity: 7,247 barrels/day

Bio-oil Processing capacity: 1,382 tons/day

Hydrogen added to the 1st hydrotreatment step: 5.4 kg H2/kg bio-oil

Hydrogen consumed in 1st hydrotreatment step: 0.166 kg H2/kg bio-oil

Hydrogen added to the 2nd hydrotreatment step: 12.77 kg H2/kg bio-oil

Hydrogen consumed in the 2nd hydrotreatment step: 4.07 kg H2/kg bio-oil

Gasoline Produced: 6 678.3 lb/h

Jet Fuel Produced: 18 624 lb/h

Diesel Produced: 12 379 lb/h

Hydrogen Produced: 8 884 lb/h

CO2 released: 350.2 tons/day

[1]Jones S, Meyer P, Snowden-Swan L, Tan e, Dutta A, Jacobson J, Cafferty K: Process design and economics for Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels. Prepared for the US. Department of Energy Bioenergy Technologies Office. PNNL-23053, NREL/TP-5100-61178, November 2013

Summary of Progress

Alternative Jet Fuel Technologies

Pyrolysis Unit

Capacity: 500 dry tons/day

Feedstock cost: 80 $/dry tons

Number of workers: **31** (124 in four pyrolysis units)

Capital Investment: $ 25,749,000 ($ **102,996,000** for four units)

Feedstock: $ 13,440,000 / year **(48.73 %)**

Depreciation and financing: $ 4,635,000/year

Salary + benefits: $ 2,280, 960 / year

Utilities : $ 2,606,343/ year

Maintenance and repair: $ 1,802,445 / year

Property insurance: $ 257,492/ year

Local Taxes: $ 514, 984/ year

Overhead: $ 2,041,702/ year

Total Manufacturing cost: **$ 27,578, 829/ year**

Bio-oil Produced: 25,567,543 gallons/year

Breakeven price: 1.07 $/gallons

Bio-oil refining[1]

Capacity: 1,383 tons/day (7,247 barrels/day)

Feedstock cost: 1.07 $/gallons

Number of workers: **83**

Capital Investment: **$ 179,415,865**

Feedstock: $ 118,341,202 / year **(69,44 %)**

Depreciation and financing: $ 28,720,850 /year

Salary + benefits: $ 4,288,938 / year

Utilities : $ 4,972,271/ year

Maintenance and repair: $ 5,382,476/ year

Property Insurance: $ 1,255,911/ year

Local Taxes: $ 3,588,317/ year

Overhead: $ 3,860,044/ year

Total Manufacturing cost: **$ 170,410,011/ year**

Gasoline Produced: 8,676,737 gallons/year

Jet Fuel Produced: 23,698,954 gallons/year

Diesel Produced: 14,958,576 gallons/year

Average breakeven price: 3.6 $/gallons

[1]Jones S, Meyer P, Snowden-Swan L, Tan e, Dutta A, Jacobson J, Cafferty K: Process design and economics for Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels. Prepared for the US. Department of Energy Bioenergy Technologies Office. PNNL-23053, NREL/TP-5100-61178, November 2013

Summary of Progress
Technologies in Existing Infrastructure

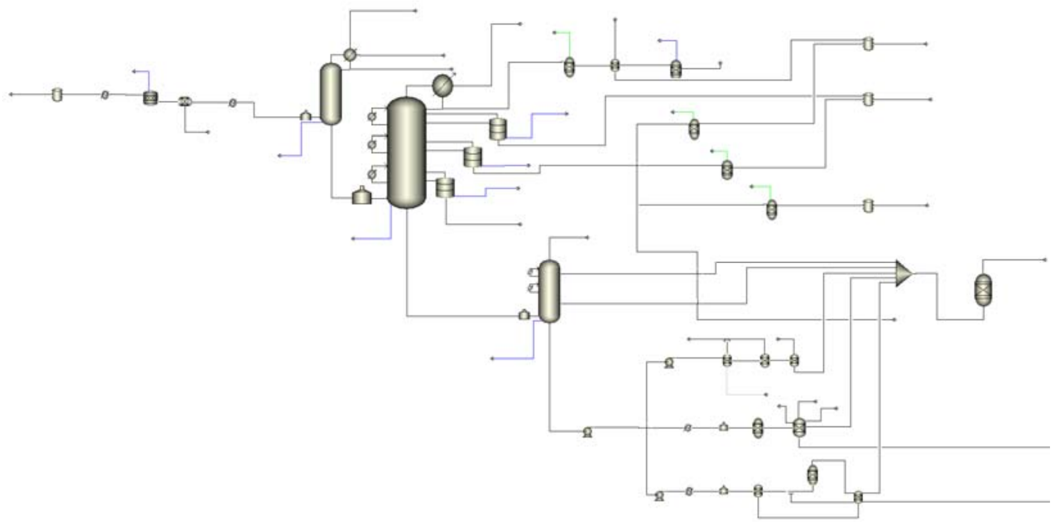
Petroleum Refineries

Aspen Plus ® simulation of a 100,000 barrels/day refinery processing Cusiana (API = 36.35º)

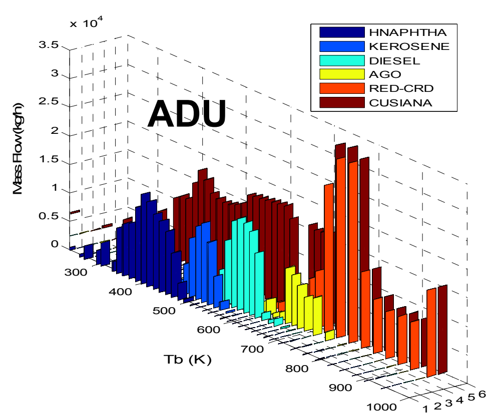
Main units: (1) Desalting, (2) CDU, (3) Kerosene/Jet Hydrotreater, (4) Diesel hydrotreater, (5) Naphtha hydrotreater, (6) Catalytic Reformer, (7) Cont. Catalytic Regen, (8) Isomerization, (9) Alkylation, (10) Catalytic Polymerization, (11) Gas Plant

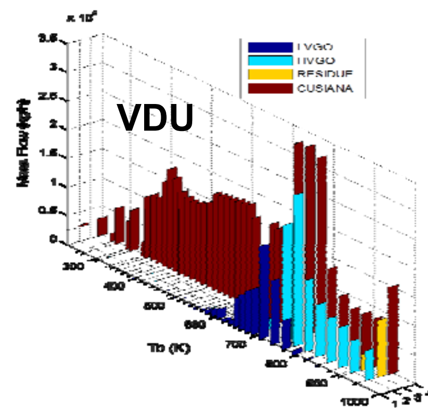
Main Products: LPG, Gasoline, Jet Fuel, Diesel, Coke, Sulfur

Crude Oil Refinery Flow Diagram (Aspen Plus Simulation)



Distribution components ADU and VDU





Summary of Progress

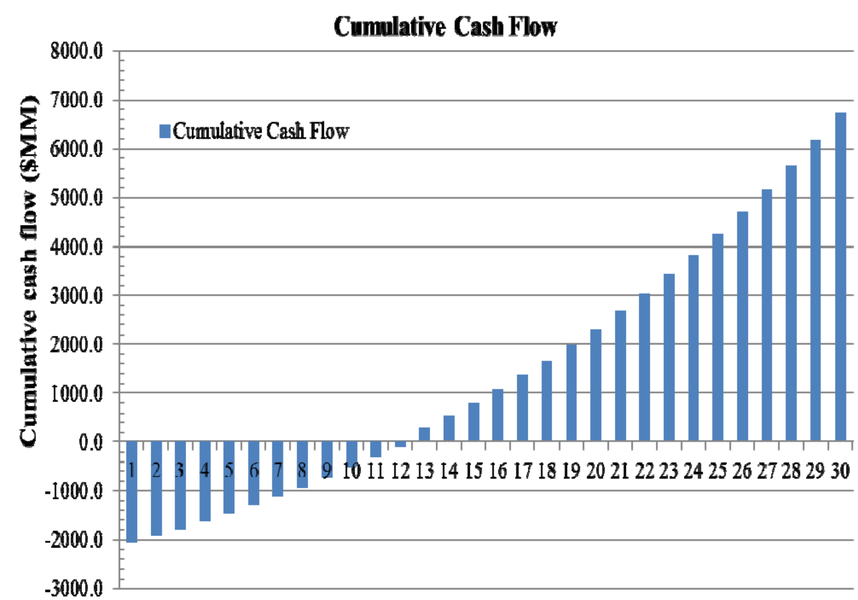
Technologies in Existing Infrastructure

Capacity: 100,000 barrels/day

Capital Expenditure (2014): $ 1,946 millions

Products sale: $ 3,928 millions

Expenditure	**$ MM/year**
Crude	3,621
N-butane	14.3
Energy consumption	11.5
Steam	0.82
Natural Gas	0.02
Water	13.5
Operating supplies	0.03
Royalties	0.37
Catalyst	1.4
Salaries and Wages (150 workers)	15.0
Maintenance	14.8
Insurances	3.7
Capital Cost (Year 1 – 13)	230.1
Total Operating Cost (AOC) (years 1-13)	**3,927**



Summary of Progress

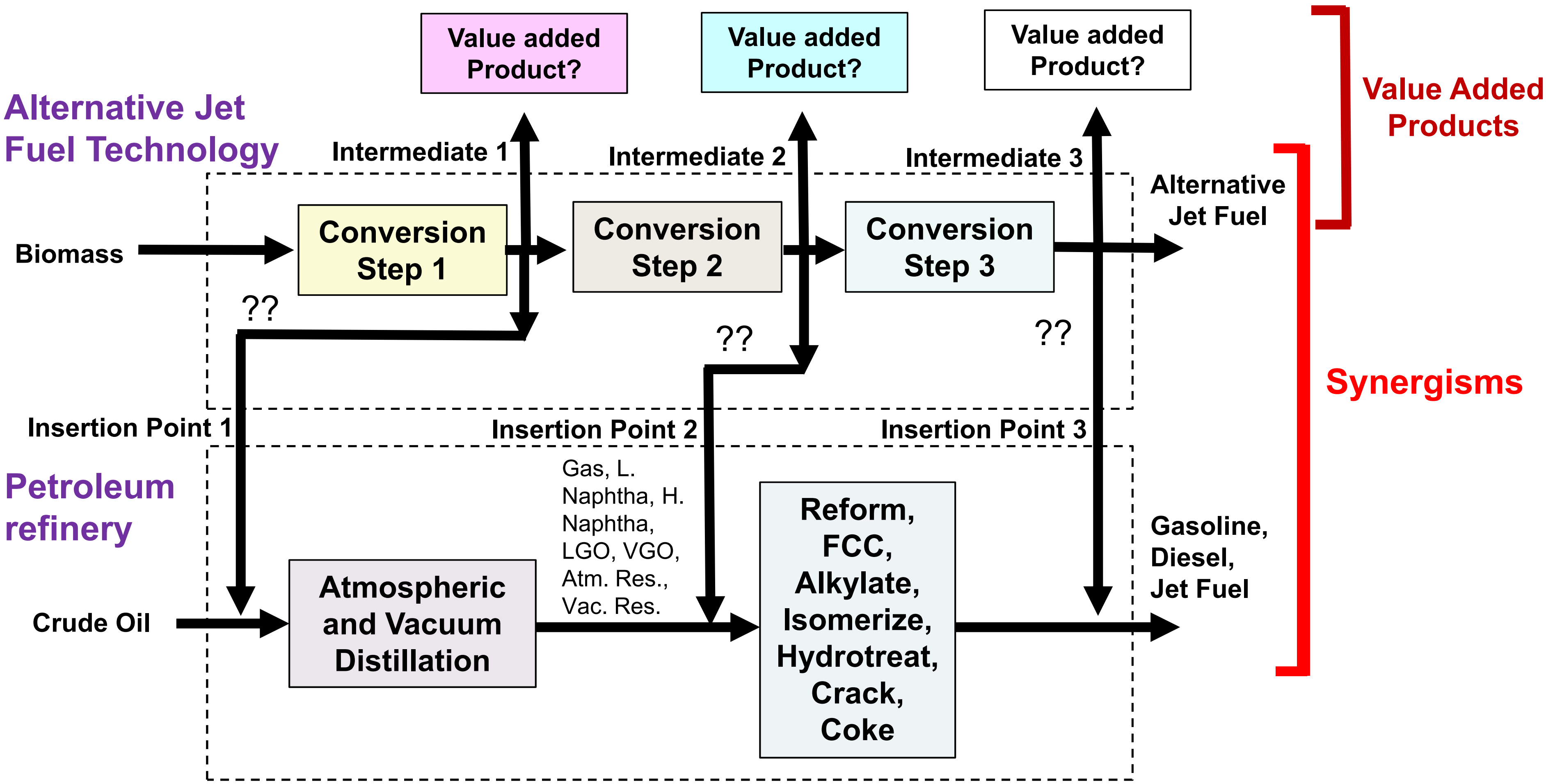
Location of Industrial Infrastructure

US can be divided in regions dominated by a certain industrial infrastructure that can be leveraged for the Production of Alternative Jet Fuels. This existing infrastructure may provide economic and technical advantages that could eventually lead to the development of distinctive bio-refinery technologies in each of these regions.

Summary of Progress

Synergisms and High Value Products

We are planning to follow an approach similar to the one used by PNNL to study synergisms between Pyrolysis and Petroleum refineries.

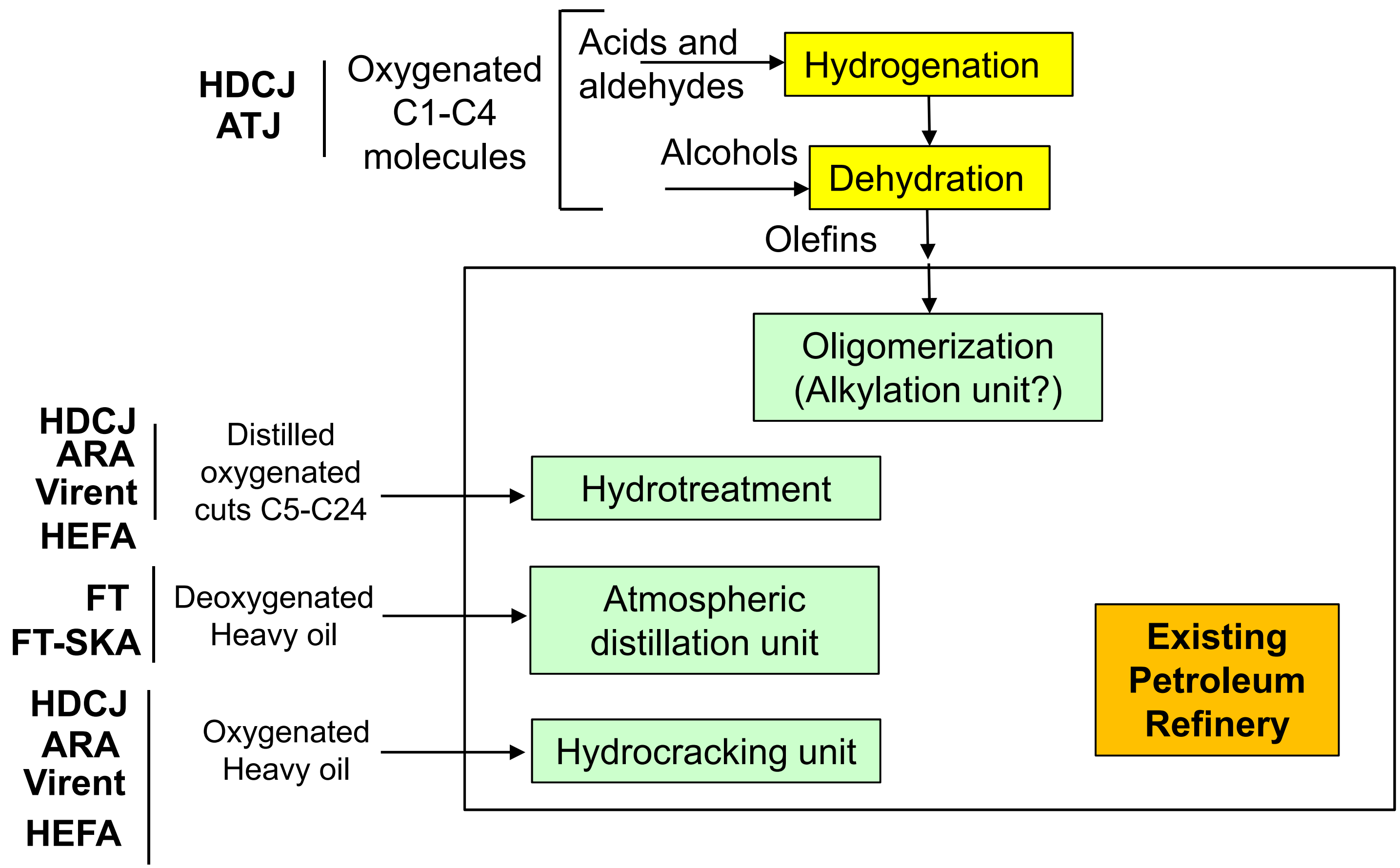


Source: Holladay J. Refinery integration of Renewable feedstocks. CAAFI R&D SOAP-Jet webinar series November, 2014

Source: Freeman CJ, Jones SB, Padmaperuma AB, Santosa M, Valkenburg C, Shinn J: Initial Assessment of U.S. Refineries for Purpose of Potential Bio-based Oil Insertions. US Department of Energy under contract DE-AC-AC05-76RL01830. PNNL-22432

Summary of Progress

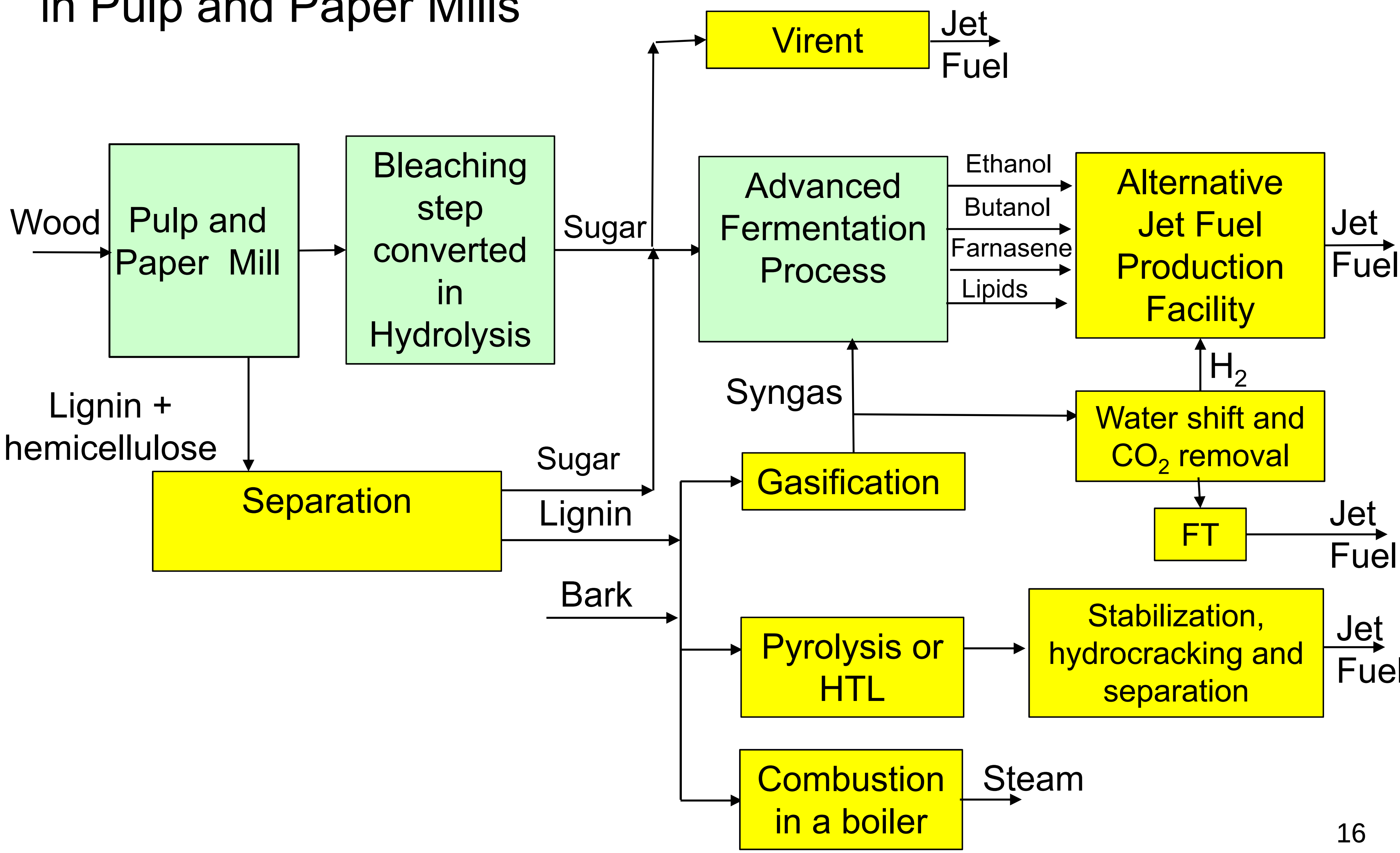
Bio-refinery Concept for the Production of Jet Fuels in Petroleum Refineries



How can we be talking of alternative feedstocks for a petroleum refinery at this time when the petroleum prices is at 40 $/barrel? This scenario is possible if the petroleum industry if forced to pay for the reposition costs!

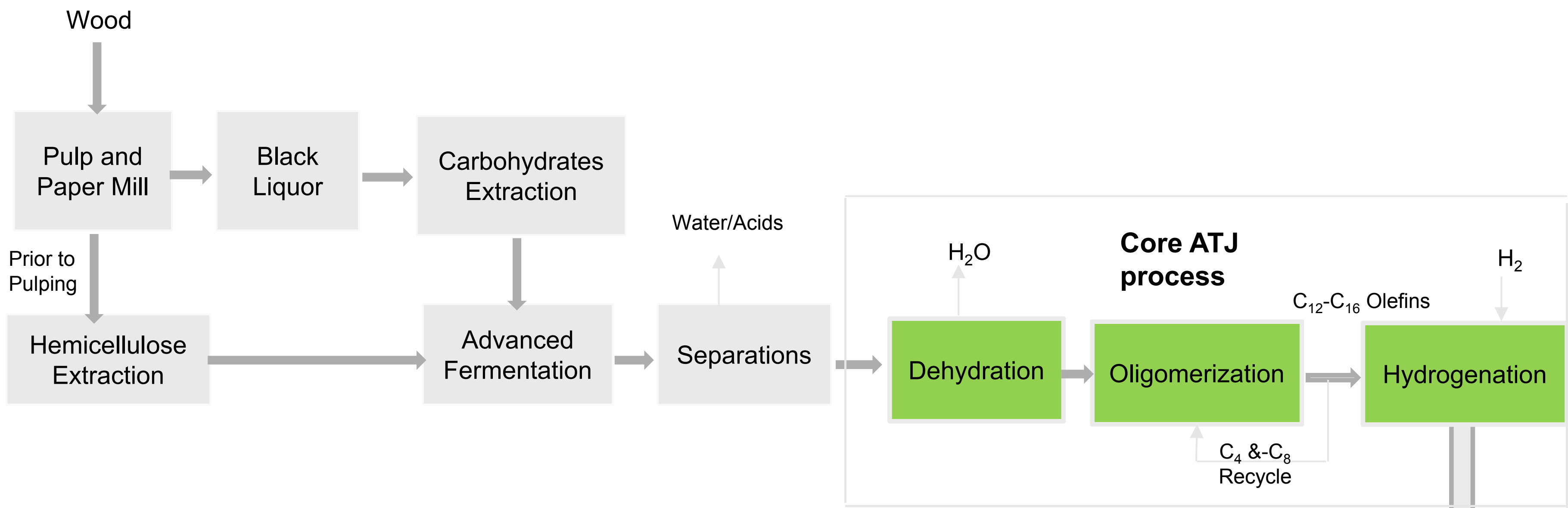
Summary of Progress

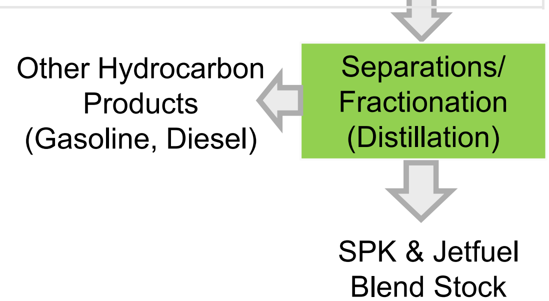
Bio-refinery Concept for the Production of Jet Fuels in Pulp and Paper Mills



Summary of Progress

Example: Pulp & Paper Mill Integration with ATJ Process





<u>Paper mill Resources for Retrofitting and Integration with ATJ process to Produce Jet Fuel</u>

Exploring the possibilities of using paper mill resources:

Bleach/Surge Tanks – 100 ° C
Superheater – 480 ° C
Pumps – 15hp and above
Sulfite Process Digester- 170 ° C (Dehydration)
Evaporator -120 ° C, 10 bar , Retrofitting to Fixed bed catalytic reactor (Oligomerization)
Recovery Boiler Units - 480 ° C (Fractional Distillation)
Digester - 170 ° C, 15 bar (Hydrogenation using Catalysts)

Summary of Key Accomplishments Since Last Update

- Last Update: March, 2015

Key accomplishments since your last update.

(1) This project served as the subject of five capstone projects for 22 senior Chemical Engineering students.

(2) The first draft of the 10 design cases was or is under review by peers from the Industry and the National Labs.

(3) The revised design cases will soon be submitted to external review by Industrial Experts (**The team is now looking for external industrial reviewers**).

(4) We are now ready to start working in the analysis of regional supply chains with **standalone jet fuel production technologies**.

(5) Several bio-refinery concepts for the **production of jet fuels taking advantage some of the existing infrastructure** in the pulp and paper, sugarcane industry, corn ethanol and pulp and paper were proposed.

Next Steps (Year 2)

Use the **design cases for standalone AJF production technologies** developed last year in the analysis of **regional supply chains**.

Write a **literature review paper** on standalone AJF production technologies (this will require the integration of the information collected in the different design cases).

Use the design cases for standalone AJF production technologies to conduct a **comparative TEA analysis**.

Evaluate the integration of selected AJF pathways with **existing industrial infrastructure** (Petroleum Refinery, Pulp and Paper Mill, Sugarcane Mills, Corn Ethanol)

QUESTIONS AND ANSWERS