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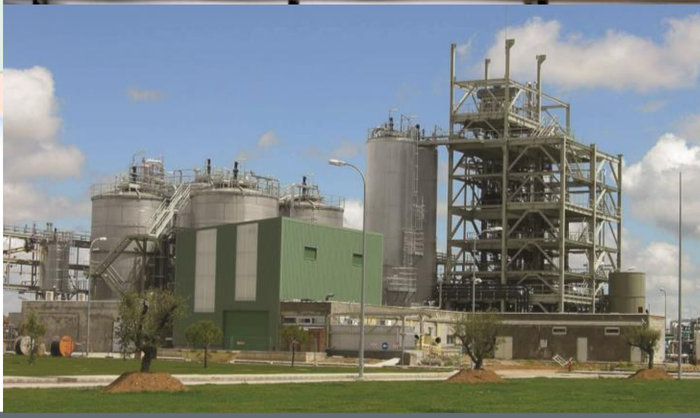


Drop-In Biofuels:
The Key Role of Co-Processing

May 28, 2019

Jim Spaeth

Advance Development & Optimization

Program Manager

Discussion Points

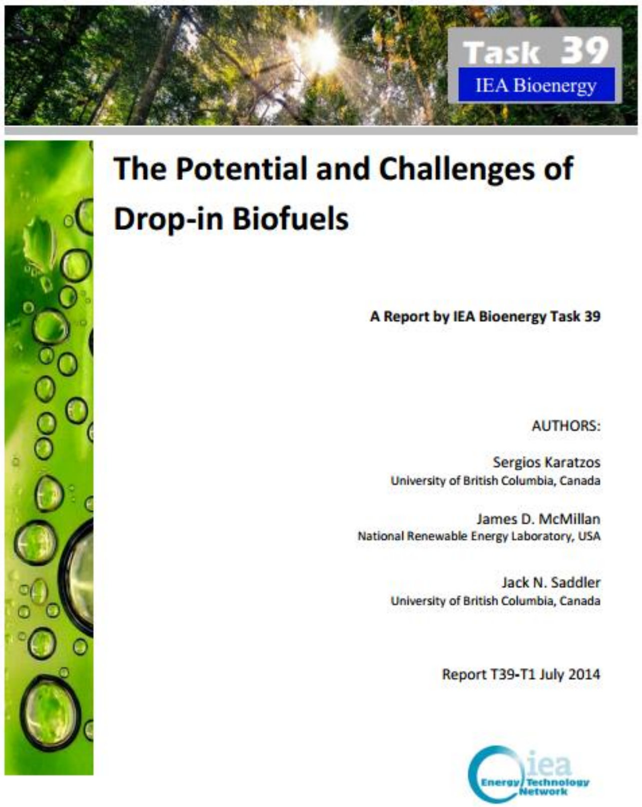
- Definition of Drop-In Biofuels
- Technologies for Drop-In Biofuels
- Co-Processing Insertion Points
- Oleochemical Drop-Ins
- Thermochemical Drop-Ins
- Challenges of Technology Platforms
- How to Expand Drop-in Biofuel Production
- Potential Impact of FCC Co-Processing

Commissioned Report Published by IEA Bioenergy

Commercializing Conventional and Advanced Liquid Biofuels from Biomass

Task 39 IEA Bioenergy

www.task39.org



Task 39 IEA Bioenergy

The Potential and Challenges of Drop-in Biofuels

A Report by IEA Bioenergy Task 39

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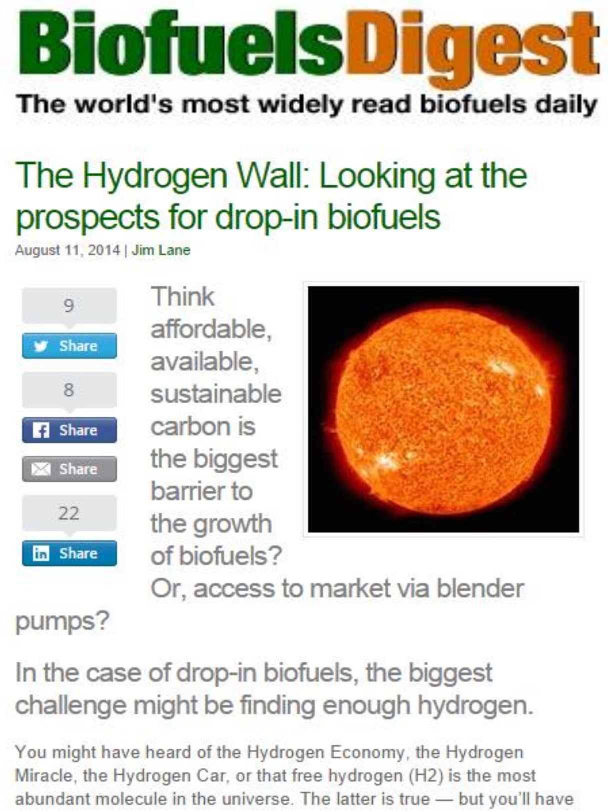
Report T39-T1 July 2014

iea Energy Technology Network



BiofuelsDigest

The world's most widely read biofuels daily

The Hydrogen Wall: Looking at the prospects for drop-in biofuels

August 11, 2014 | Jim Lane

9 Share 8 Share Share 22 Share

Think affordable, available, sustainable carbon is the biggest barrier to the growth of biofuels? Or, access to market via blender pumps?

In the case of drop-in biofuels, the biggest challenge might be finding enough hydrogen.

You might have heard of the Hydrogen Economy, the Hydrogen Miracle, the Hydrogen Car, or that free hydrogen (H2) is the most abundant molecule in the universe. The latter is true — but you'll have

Thank You to Susan van Dyk, Jianping Su, Jim McMillan, Jack Saddler and Task 39

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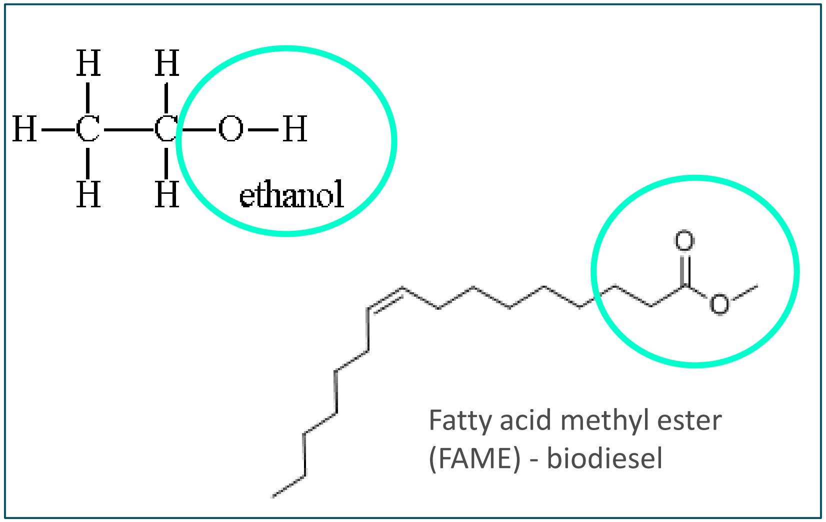
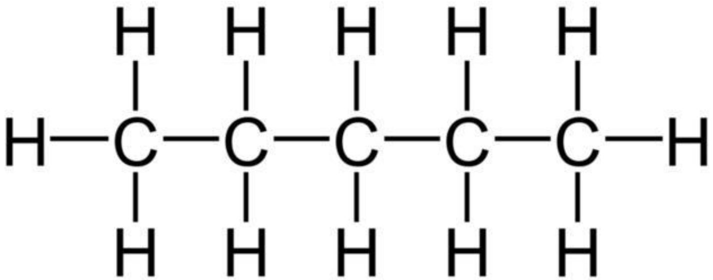
Definition of "Drop-In" Biofuels

- Drop-in biofuels: are liquid bio-hydrocarbons that are:
  - functionally equivalent to petroleum fuels and
  - fully compatible with existing petroleum infrastructure

Current biofuels vs Drop-in fuels





- Hydrotreated vegetable oils (HVO) or HEFA
- Hydrotreated pyrolysis oils (HPO)
- Fischer-Tropsch liquids

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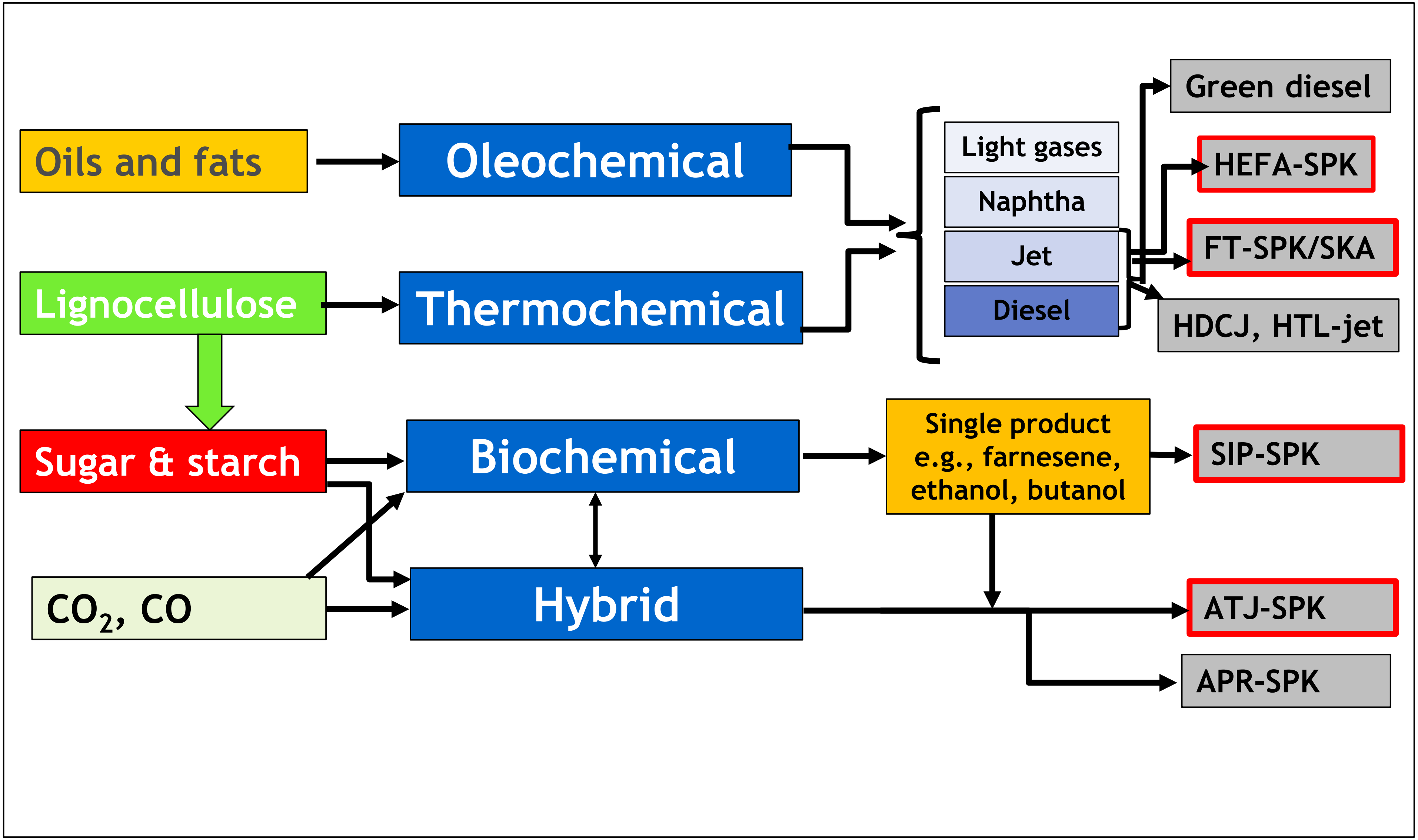
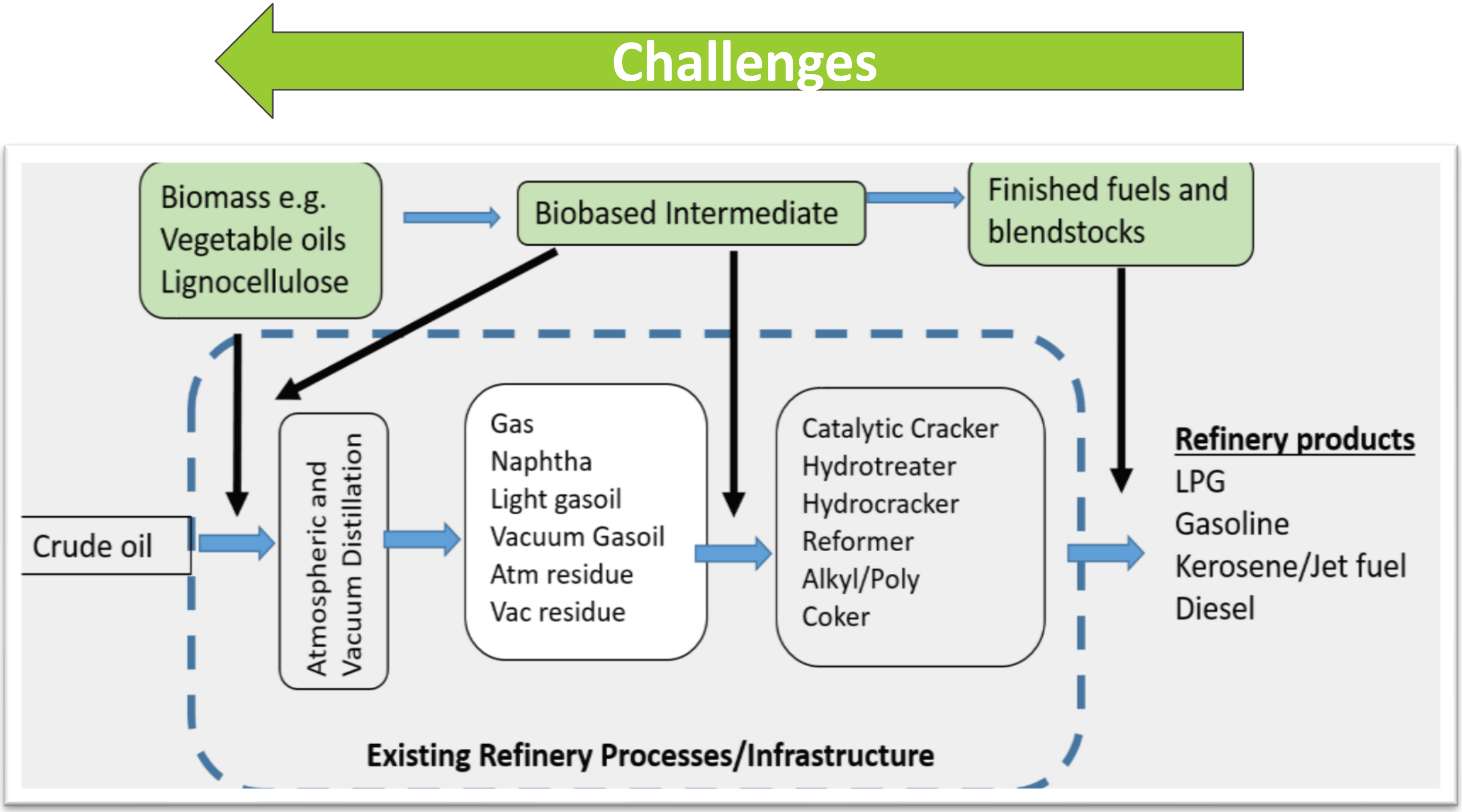
Technologies for Drop-in Biofuel Production



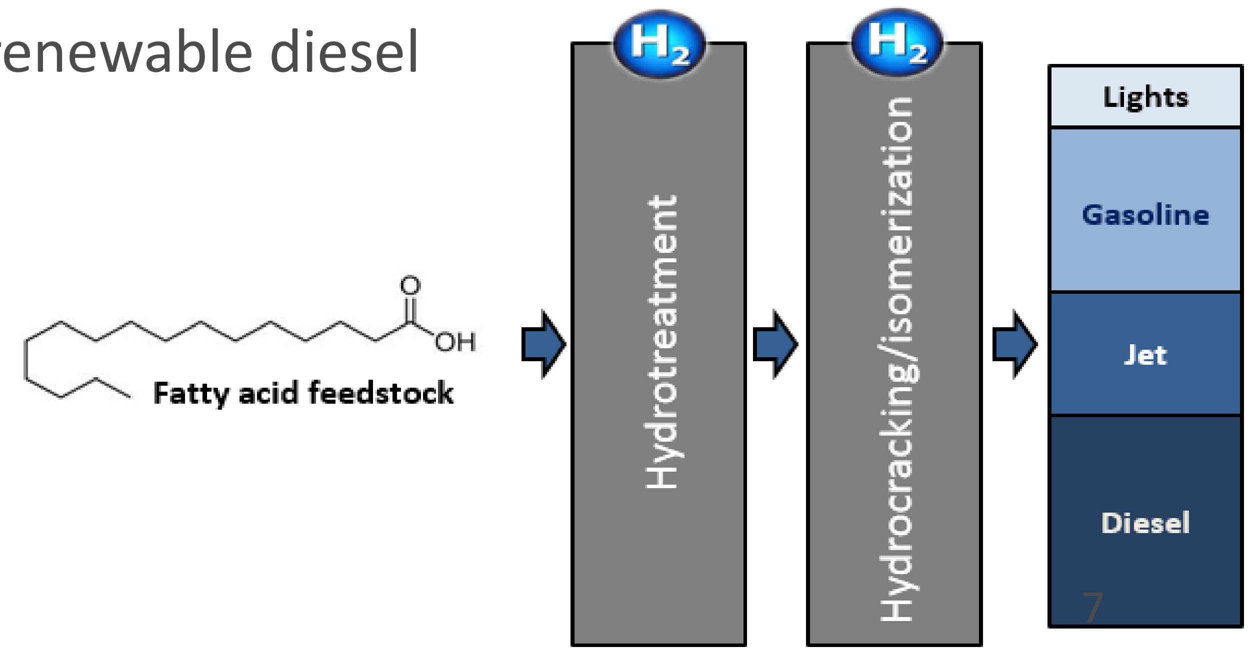
Co-Processing Potential Insertion Points



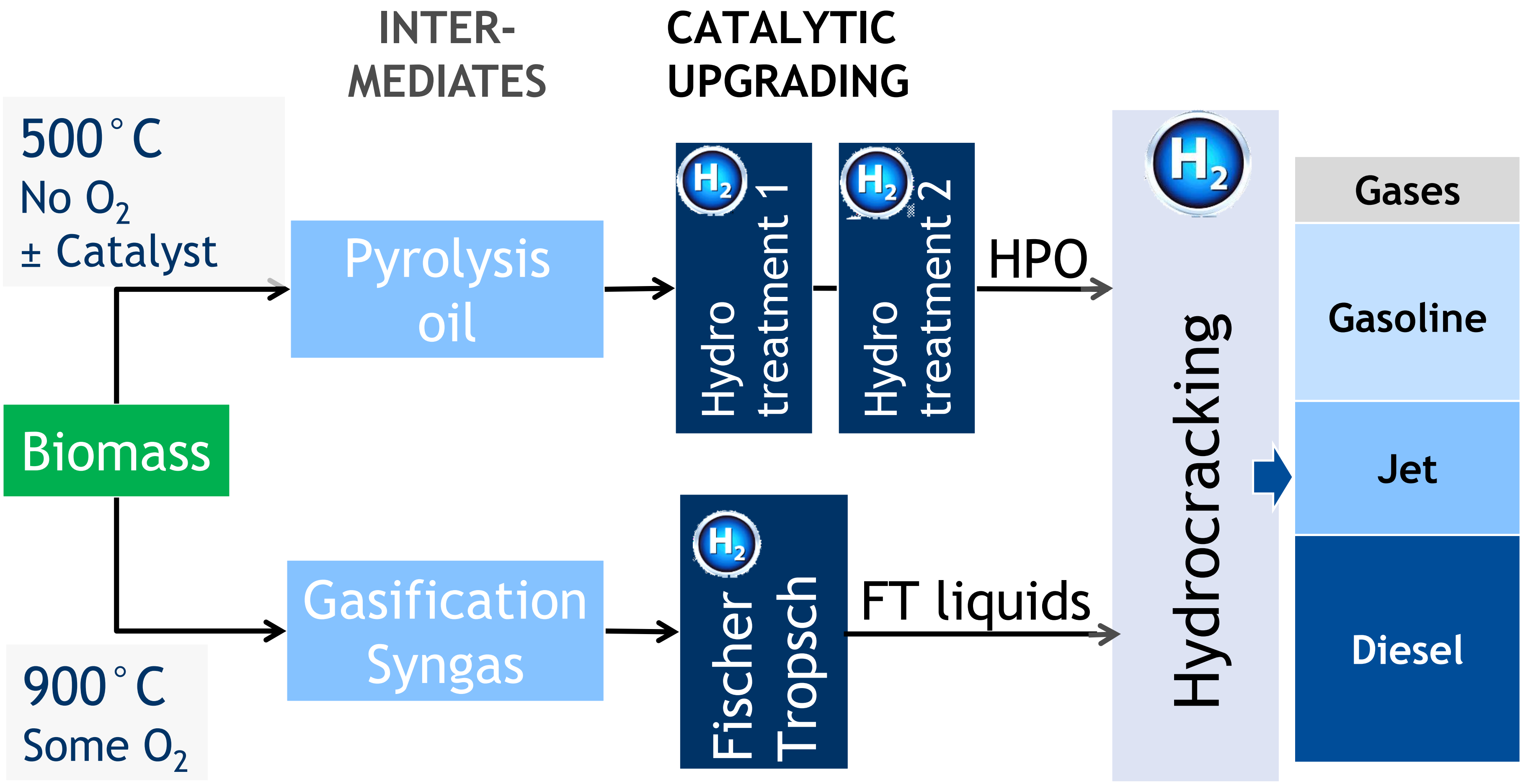
Co-processing strategies illustrated as various potential insertion points into a generic petroleum refinery

Oleochemical Drop-In Biofuel Platform

- Products – HVO, HEFA, HDRD, HRJ
- "Simple" technology, low risk (already commercial)
  - ASTM certification in 50% blends
- Hydrotreatment of lipid feedstocks (vegetable oils, used cooking oil, tallow, inedible oils)
- Lowest H_2 requirement
- Blended product – renewable diesel



Thermochemical Drop-in Biofuel Platforms



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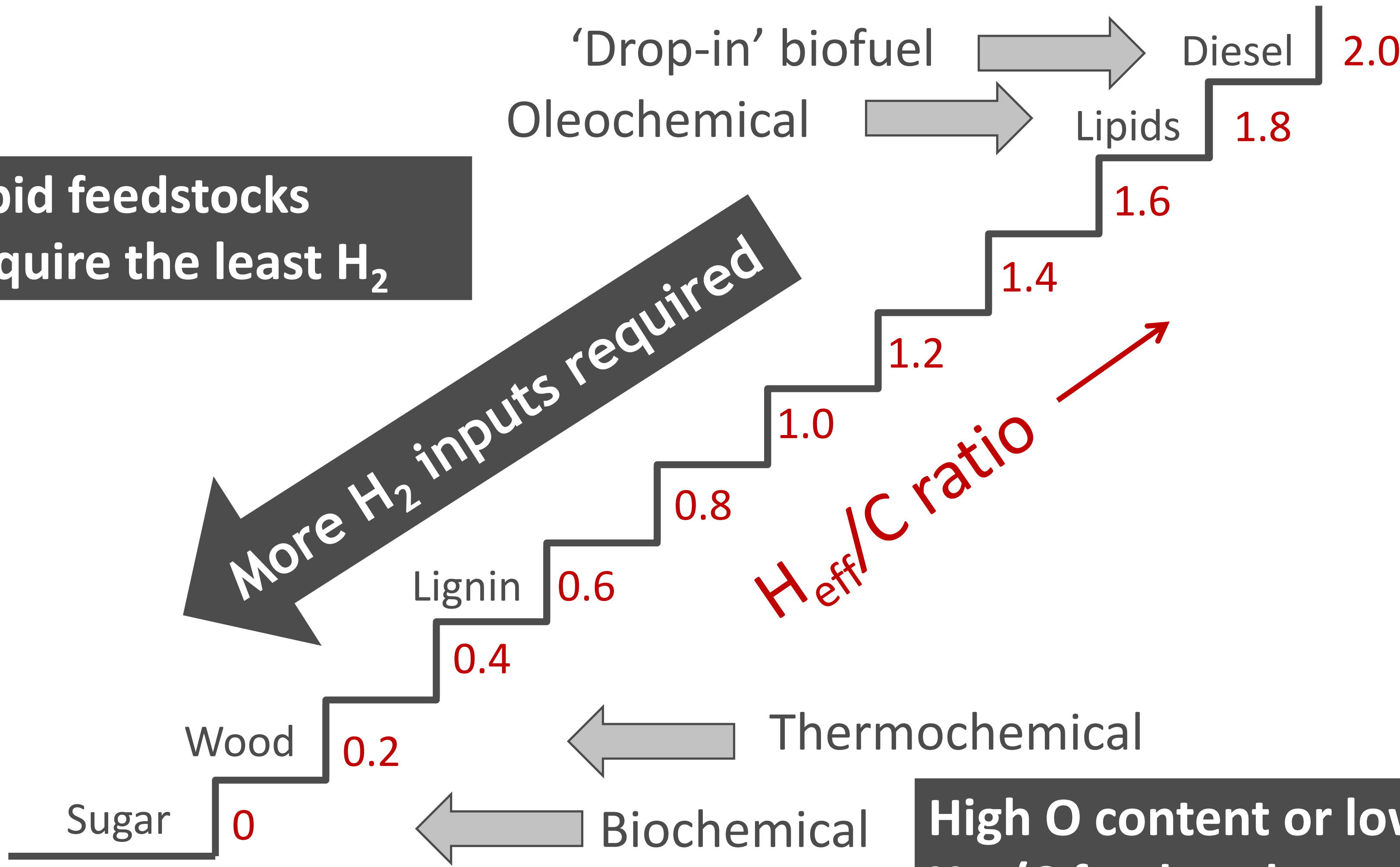
Key Challenge – Reducing Oxygen Content



Lipid feedstocks require the least H_2

High O content or low H_{eff}/C feedstocks require more H_2 inputs

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Challenges of Technology Platforms

- Oleochemical
  - Feedstock cost, availability, sustainability
- Pyrolysis
  - Hydrogen
  - Hydrotreating catalyst – cost and lifespan
- Gasification
  - Capital / scale
  - Syngas conditioning
- Biochemical
  - Low productivity
  - Valuable intermediates

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How do we Expand Drop-in Biofuel Production?

- Build stand-alone infrastructure
- Co-location (hydrogen)
- Repurpose existing infrastructure
  - e.g., World Energy (formerly AltAir) in California
- Co-processing of biobased intermediates in existing refineries to produce fossil fuels with renewable content (lower carbon intensity)

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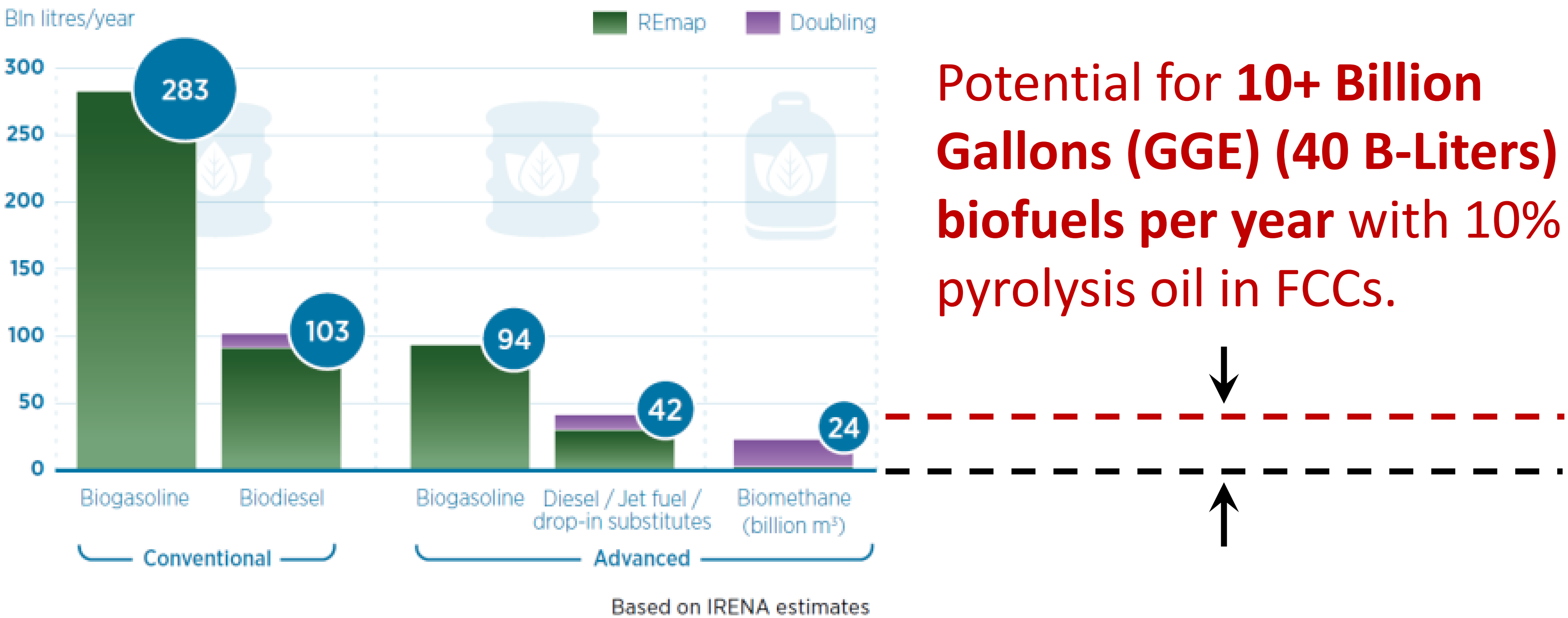
Relevance: Potential Impact of FCC Co-Processing

	United States	Global
FCC Processing Capacity (Bbl / Day)	6.0 Million	14.6 Million
Biofuels at 5 Wt% Pyrolysis Oil (B-GGE / Year)	1.0 – 2.8	2.4 – 6.8
Biofuels at 10 Wt% Pyrolysis Oil (B-GGE / Year)	2.0 – 4.4	4.9 – 10.7
Biofuels at 20 Wt% Pyrolysis Oil (B-GGE / Year)	5.0 – 6.3	12.1 – 15.2

IRENA Renewable Energy Roadmap 2016



Potential for **10+ Billion Gallons (GGE) (40 B-Liters) biofuels per year** with 10% pyrolysis oil in FCCs.

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European Commission/IEA Bioenergy Task 39 Workshop

- May 15th and 16th IEA TCP Task 39 Business Meeting held at the EC's Joint Research Centre (JRC) in northern Italy
- Followed immediately by a workshop: "Biofuels Sustainability – Focus on Lifecycle Analysis" (LCA)
- Sub-topics covered in the workshop
  - Biofuel certification
  - Advanced biofuel developments: focus on co-processing
  - Uncertainty (i.e., sources of error) in LCAs
  - Availability of sustainable feedstocks: complementarity vs competition
  - Drop-in fuels
  - Update on significant topics in LCA and sustainability

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European Commission/IEA Bioenergy Task 39 Workshop

- Summary of companies and organisations represented at the workshop (in addition to Task 39 experts):
  - ISCC, SGS, RSB: leading global biofuel certification companies
  - European Biodiesel Board: EU biodiesel industry association
  - Haldor-Topsoe: global hydroprocessing technology company
  - Institut Ruđer Bošković: fuel carbon dating specialists
  - Neste (Finland) and REG (USA): leading biofuel producers
  - Fulcrum: pioneering MSW to biofuel company
  - Bauhaus Luftfahrt: future aviation technologies experts
  - LBST: world-class bioenergy LCA experts
  - UPM: bio-industry specialists from forest feedstocks
  - TOTAL, ENI: large fossil fuel companies in the EU

Thank you

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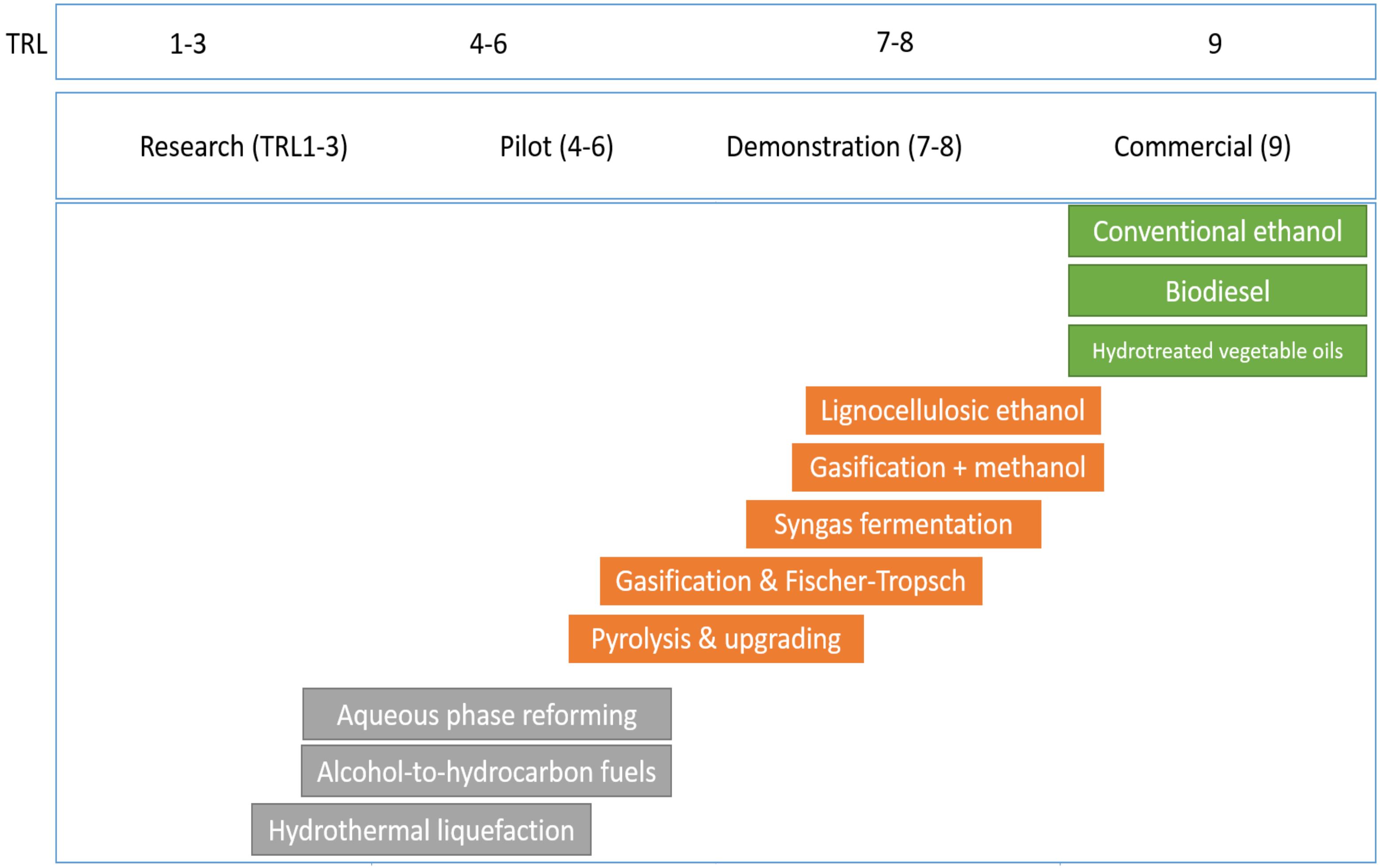
Additional Slides

Stages of Commercialisation



Critical Research Needs for Co-processing (HT/FCC)

- Minimal studies to date on co-processing via either pathway
- Preliminary TEA shows co-processing via FCC and HC/HT is economically viable
- Significant gaps exist
  - Impact of organic oxygenates on:
    - FCC and HC/HT chemistry and reaction kinetics
    - Fuel product quality determined by comprehensive compositional analysis and fuel property testing
    - FCC or HC/HT catalysts and equipment
  - Impacts:
  - Of fossil feedstock composition variation on process yields and operations when blended with bio-derived intermediates
  - Of using fossil feedstocks beyond VGO
  - Of CO, CO_2, and H_2O on refinery operation
  - Biogenic carbon tracking

Petrobras/NREL FCC Co-Processing Data

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, d= 2"

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

Andrea de Rezende Pinho [a,*], Marlon B.B. de Almeida [a], Fabio Leal Mendes [a], Vitor Loureiro Ximenes [a], Luiz Carlos Casavechia [b]

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[b] PETROBRAS-SIX, Rodovia do Xisto BR 476, km 143, São Mateus do Sul, PR, Brazil

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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[c] NREL – National Renewable Energy Laboratory, 15013 Denver West Parkway Golden, CO 80401-3305, USA

Petrobras/NREL FCC Co-Processing Outcomes

- Up to 10 wt% of FP bio-oils can be co-fed with VGO with 2-3 wt% biogenic carbon captured in produced gasoline
- Feeding bio-oils at > 10 wt% negatively impacted both process and product
  - Due to the high oxygenate content of the bio-oil (50% oxygen), ***although the associated composition and relevant chemistry has not been determined***
- TEA of the Petrobras results showed that:
  - ***FCC co-processing can reduce the overall costs of biofuels production*** for both target and state of technology (SOT) scenarios relative to the full pathway minimum fuel selling price (MFSP)
  - ***Bio-oil producers and petroleum refiners have opportunities to realize shared profitability***, beyond the 10% IRR assumed for the MSP calculations, for co-processing when crude oil prices are as low as $65 per barrel co processing FP oils without policy credits

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Ongoing Industrial Activities

- UOP/Andeavor (Tesoro)/Ensyn Commercial Demonstration
  - Co-processing Ensyn bio-oil in FCC at Andeavor's Martinez CA refinery
  - Preliminary run planned for2019 at low blend level (c.a. 1 vol%)
    - Test feeding system (UOP design)
    - Validate maintenance of catalyst activity
  - Demonstration run planned for 2019 at Martinez
    - Higher blend level (c.a. 5%)
    - Support from NREL (yield/mass balance calculations) and PNNL (LCA)
- CARB rolling out guidelines for LCFS credits for co-processing of bio-oil and other renewable oils in refinery unit operations
    - Co-processing in FCC and HT both initially included
    - NREL & PNNL have strong advisory role to CARB on co-processing
- CEC grant to NREL for co-processing route to bio-jet