THE POTENTIAL AND CHALLENGES OF 'DROP-IN' BIOFUELS:

The key role that co-processing will play in its production

Susan van Dyk, Jianping Su, James McMillan and Jack Saddler

Forest Products Biotechnology/Bioenergy Group

International Energy Agency Bioenergy Task 39 (Liquid biofuels)

Task 39
IEA Bioenergy

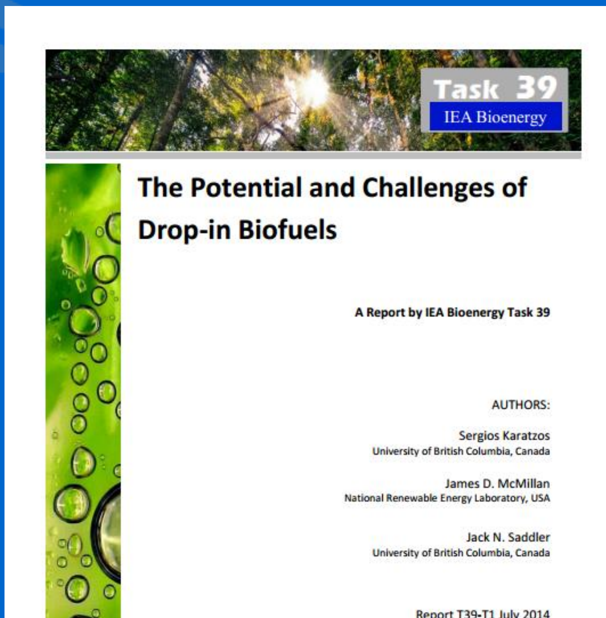
Forest Products Biotechnology/Bioenergy (FPB/B)

UBC

Commissioned report published by IEA Bioenergy Task 39 (2014)

Commercializing Liquid Biofuels from Biomass

Task 39 IEA Bioenergy



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

www.Task39.org

Envergent Technologies A Honeywell Company

UOP A Honeywell Company

ENSYN

NREL NATIONAL RENEWABLE ENERGY LABORATORY

NESTE

Pacific Northwest NATIONAL LABORATORY Proudly Operated by Battelle Since 1965

Enerkem

Borregaard

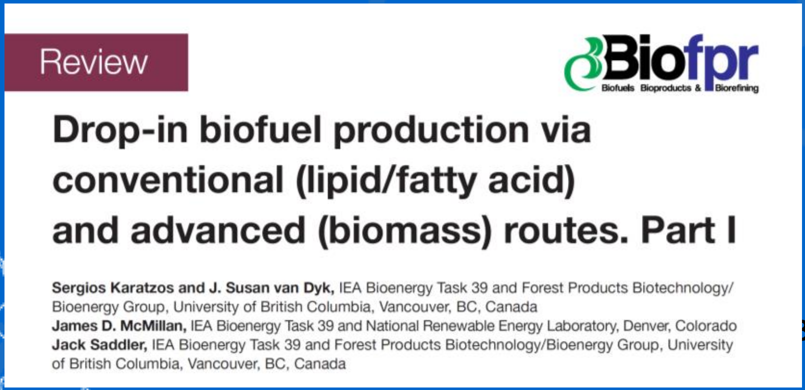
sundrop fuels

CTBE Brazilian Bioethanol Science and Technology Laboratory

Project BioTfueL

KIT Karlsruhe Institute of Technology

CHEMREC Energy to succeed



Review

Biofpr Biofuels Bioproducts & Biorefining

Drop-in biofuel production via conventional (lipid/fatty acid) and advanced (biomass) routes. Part I

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bioenergy2020+

AMYRIS

SINTEF

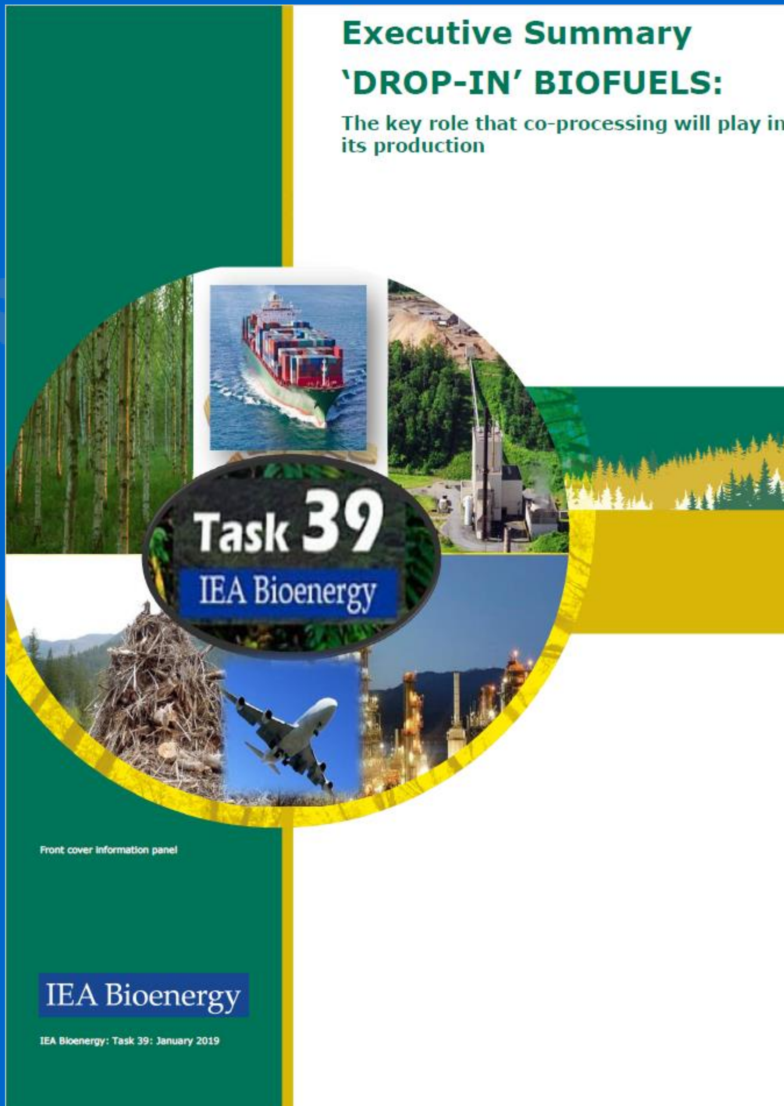
gevo

Swedish Energy Agency

solazyme

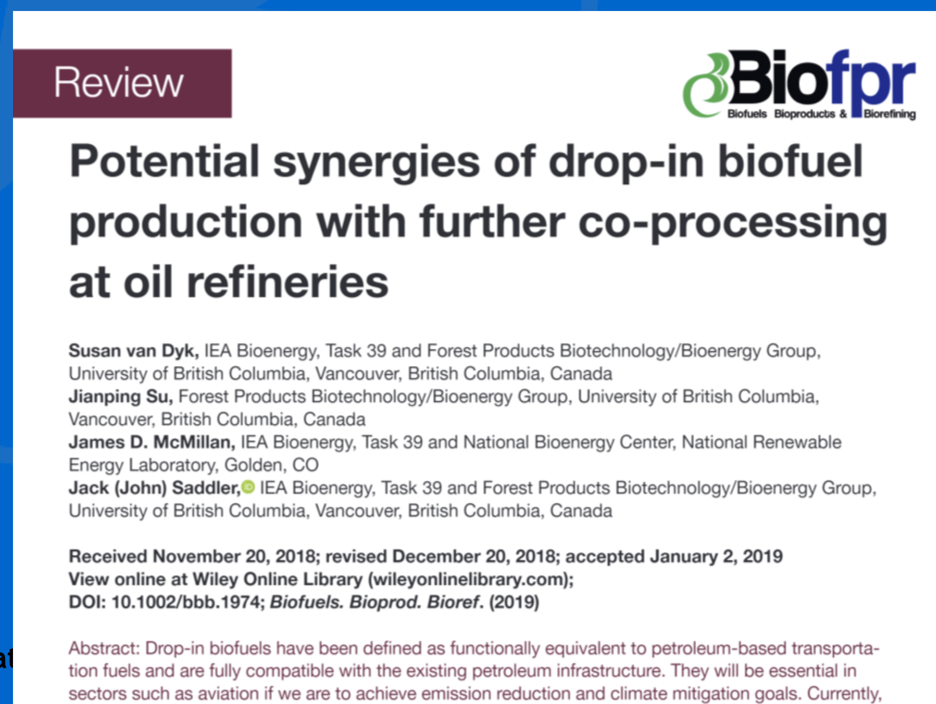
- All the conclusions from the original report is still valid
- The 2014 report provided an excellent and in-depth overview of the technologies and companies in the space

- The 2019 update builds on this, looking at recent developments and trends but with a significant focus on co-processing



'DROP-IN' BIOFUELS: The key role that co-processing will play in its production

Executive Summary available from the Task 39 website


Review

Biofpr Biofuels Bioproducts & Biorefining

Potential synergies of drop-in biofuel production with further co-processing at oil refineries

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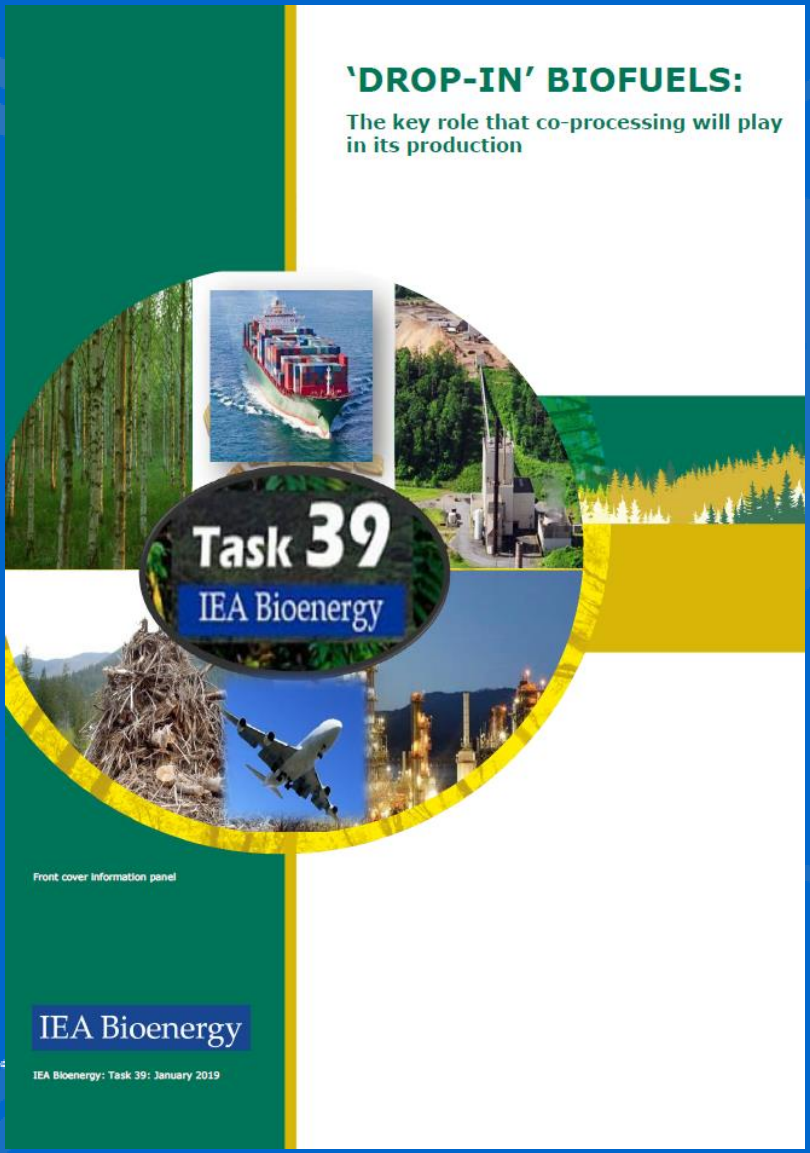
View online at Wiley Online Library (wileyonlinelibrary.com);
DOI: 10.1002/bbb.1974; *Biofuels. Bioprod. Bioref*. (2019)

Abstract: Drop-in biofuels have been defined as functionally equivalent to petroleum-based transportation fuels and are fully compatible with the existing petroleum infrastructure. They will be essential in sectors such as aviation if we are to achieve emission reduction and climate mitigation goals. Currently,

‘DROP-IN’ BIOFUELS: The key role that co-processing will play in its production



- Full report embargoed until the end of June 2019
- Available to members only on the Task 39 website

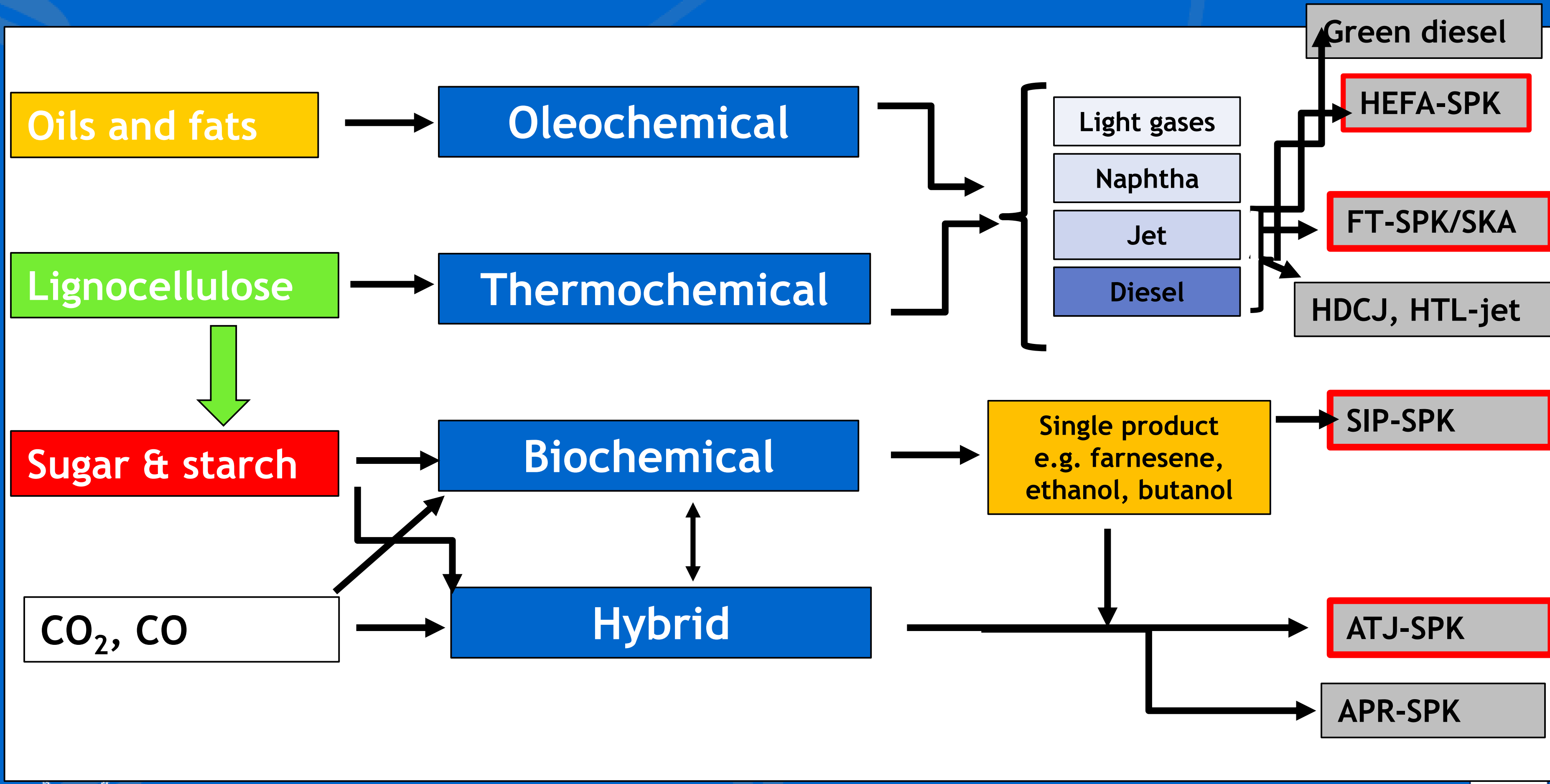
Definition of "drop-in" biofuels

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

- Definition still applicable – but does not mean that the drop-in biofuel on its own will meet all the specifications for a specific fuel product. Sometimes blending will be required

Technologies for drop-in biofuel production

- Latest technology and commercialisation developments and trends



Oleochemical drop-in biofuel platform

- Main source of commercial drop-in biofuels (~5 BL)
  - Renewable diesel
  - HEFA biojet fuel (World Energy – previously AltAir)
- Key trends
  - Conversion of existing refineries into HEFA biorefineries
    - World Energy (USA), ENI (Italy), Total (France), Andeavour (USA)
  - Move towards more sustainable feedstocks (waste & other) – increase in trade of UCO & tallow
  - Co-processing of lipids (ASTM approved for biojet)
- Key drivers & challenges
  - Policy e.g. low carbon fuel standards (California, BC)
  - Demand from aviation industry for biojet
  - Feedstock cost and availability

Thermochemical technologies

- Gasification based technologies
- Key trends
  - Plasma gasification – key projects cancelled e.g. Solena (technology too expensive although cleanest syngas)
  - Entrained (for slurries) or fluidized bed technologies
  - Municipal solid waste as cheap feedstock is a key trend
    - Enerkem commercial for methanol/ethanol production
    - Fulcrum Bioenergy (under construction - 2020) – FT liquids still need processing
  - Wood as feedstock – Kaidi (Finland), Red Rock Biofuels (USA)
- Key drivers & challenges
  - Policy
  - Aviation industry demand
  - Feedstock cost & supply chains

Thermochemical technologies

- Thermochemical liquefaction – pyrolysis, hydrothermal liquefaction
- Key trends
  - Fast pyrolysis, BTG, Ensyn – stabilization of bio-oil; progress in co-processing; multi-product focus (char & bio-oil)
  - Catalytic pyrolysis – KiOR closure; low yields; economics challenging
  - Hydrothermal liquefaction – slow progress towards commercialization (Steeper, Licella) – but co-processing of liquid products emerging as a key strategy
  - Plastics & waste as a feedstock
- Key drivers and challenges
  - Incorporation of co-processing under policies (California, BC)

Assessment of likely Technology Maturation pathways used to produce biojet from forest residues (The ATM project)

- The results from this project has demonstrated that direct thermochemical liquefaction technologies can be used successfully for upgrading into high specification finished fuels such as biojet

BOEING
NORAM
UBC
SkyNRG
BOMBARDIER the evolution of mobility
WESTJET
GARDN Green Aviation Research & Development Network

Biochemical & hybrid technology platforms

- Key trends
  - Most companies move away from biofuels towards biochemicals and bioplastic building blocks
  - Except alcohol to jet pathways – Gevo (isobutanol to jet) & Lanzatech (ethanol to jet) – both pathways received ASTM certification for biojet
  - Power to Liquids (PtL) becoming a key focus in Europe

- Key drivers
  - Aviation sector and shortage of biojet fuels
  - ASTM certification created instant access to biojet market
  - PtL driven by 100% decarbonization in transport

Commercial volumes of drop-in biofuel through oleochemical platform

Neste Oil facility, Rotterdam

Company	Location	Feedstock	Capacity
Neste	Rotterdam	Vegetable oil, UCO and animal fat	1.28 bn L/y
Neste	Singapore	Vegetable oil, UCO and animal fat	1.28 bn L/y
Neste	Porvoo, Finland	Vegetable oil, UCO and animal fat	385 m L/y
Neste	Porvoo 2, Finland	Vegetable oil, UCO and animal fat	385 m L/y
ENI	Venice, Italy	Vegetable oils	462 m L/y
Diamond Green Diesel	Norco, Louisiana	Vegetable oils, animal fats and UCO	1.04 bn L /y
UPM	Lappeenranta, Finland	Crude tall oil	120 m L/y
World Energy (AltAir)	Paramount, California	Non-edible oils and waste	150 m L/y
Renewable Energy Group	Geismar, Louisiana	High and low free fatty acid feedstocks	284 m L/y
Total	LA MÈDE	UCO and vegetable oils	641 mL/y

Co-processing as a key strategy to expand drop-in biofuel production?

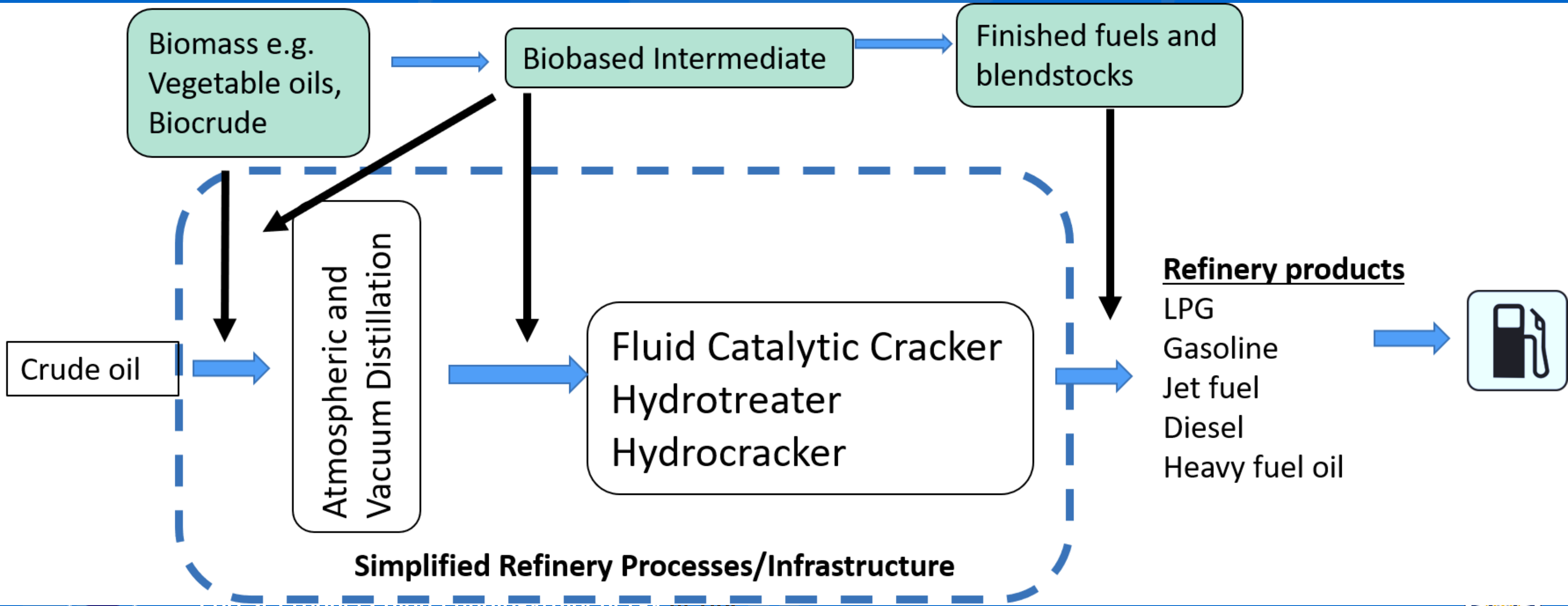
- Build stand-alone infrastructure
- Co-location (hydrogen)
- Repurpose existing infrastructure (e.g. AltAir in California)
- Co-processing of biobased intermediates in existing refineries to produce fossil fuels with renewable content (lower carbon intensity)

Decarbonisation through co-processing

Refinery participation is the key!

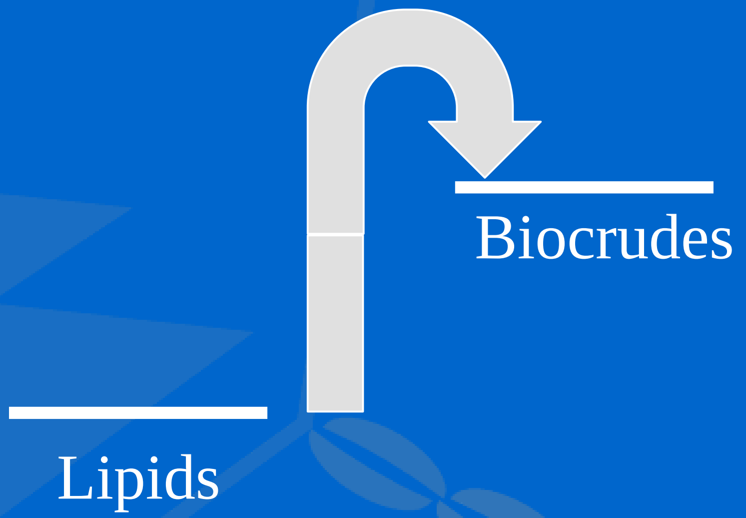
Potential insertion points of biobased intermediates

1. Atmospheric distillation – highest risk of contamination
2. Processing/finishing steps – FCC, hydroprocessing
3. Blending stage – Lowest risk



Lipids will be the initial biobased intermediate inserted into the refinery, followed by biocrudes

- Lipids easier to upgrade
- Lipids readily available (although expensive)
- Experience and derisking with a simpler feedstock to create familiarity with biobased intermediates until cheaper biocrudes become available in high volumes



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Facilitating Refinery integration and co-processing

Short-term
Lipid suppliers

Longer-term strategy
Biocrude producers

Refinery integration at

- FCC
- Hydrotreater

BC SMART ROADMAP:

A decarbonisation strategy for

British Columbia's (BC's) Marine, Aviation, Rail and Truck (MART) Sectors

Establishing the BC SMART Fuels Consortium

- This work closely linked to the drop-in update work
- Three main recommendations around co-processing
  - Refinery infrastructure
  - Policy framework
  - Establishment of a BC Fuels Consortium with multiple stakeholders

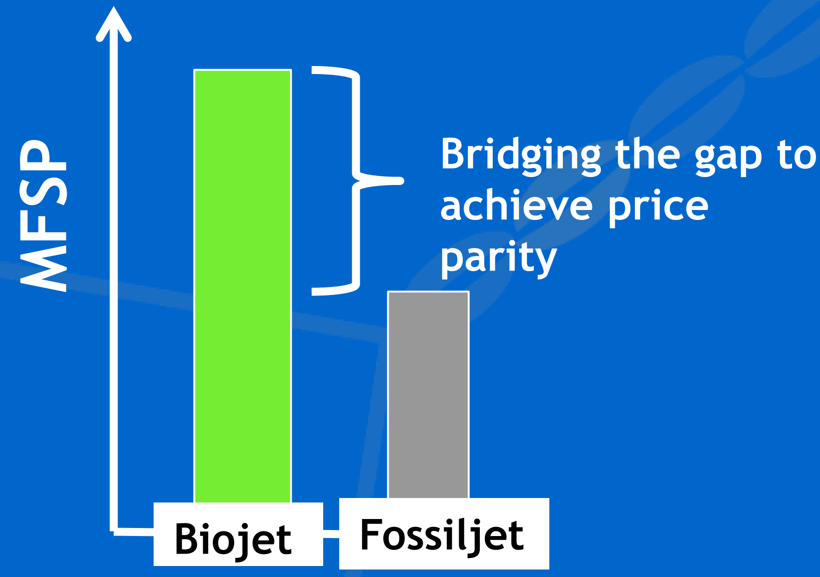
Jack Saddler, Don O'Connor,
Susan van Dyk, Mahmood Ebadian

Tracking renewable content during co-processing

- C14 isotopic method
- Potential mass balance approach
  - Total mass balance method
  - **Mass balance based on observed yields**
  - **Carbon mass balance method**

(CARB, 2017)

Role of policy



- Policy has been essential for development of conventional biofuels
- Blending mandates, Subsidies, Tax credits, market based measures (carbon tax, low carbon fuel standards)
- Drop-in biofuels will find it challenging to compete at current oil prices
- Policy to assist in bridging this price gap
- Specific policy support for drop-in fuels

Some conclusions

- Important role of policy to drive development

- Co-processing and refinery integration
  - Drop-in biofuel production more similar to oil refining
  - Multiple products
  - Similar upgrading

- Search for cheaper and more sustainable feedstock

- Demand for biojet fuels playing an important role in driving drop-in biofuel development

Follow up to the drop-in update (future work for new triennium)

Two Task 39 reports:

1) *Biojet fuels - technology, current status and policy*
2) *The ability of the marine/shipping industry to meet strict fuel sulfur limits in 2020 and the role of biofuels*

Authors: Susan van Dyk, Mahmood Ebadian, Jianping Su