Conversion of Carinata Oil into "Drop-in" Fuels & Chemicals

Carinata Summit
20 February 2018

ReadiJet™
ReadiDiesel™
ARA®

Process Background

Biofuels ISOCONVERSION Process

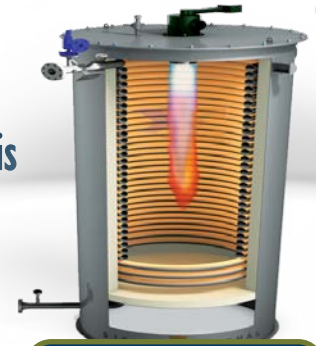
Converts fats, oils, and greases from plants, animals, or algae into “drop-in” renewable fuels

ARA

CLG
Chevron Lummus Global

Catalytic Hydrothermolysis

- Supercritical water process
- Produces crude oil that contains the same hydrocarbon types as petroleum crude



2 Minutes
Converts fats oils and greases to crude oil

Hydrotreating

- Saturates olefins
- Removes residual oxygenates

Conventional
Refinery Processes

Fractionation

- Produces finished fuels
- Jet and diesel that meet
- Meets petroleum specs without blending
- Renewable chemicals, and naphtha

First Flight Test conducted on 100% "Drop-in" ReadiJet®

- Feed stock was carinata oil
  - Produced under Air Force Contract
- National Research Council Canada
  - 29 October 2012
  - Falcon 20 Aircraft
  - Ground tests on GE 700 2D2 Turbofan
- Operation on ReadiJet® at 30,000 ft
  - 20 minutes of operations
  - Variable thrust settings
  - In-flight engine shutdown and relight
  - In-flight emissions measurements
- Performed better than Jet A
  - Specific fuel consumption was lower
  - Reduction in black carbon, oxides of nitrogen and aerosol emissions

SECNAV
F-18 Flight Test
100% CHCJ-5

Nine
F-18 Flight Tests
Completed

V-22 Osprey Flight Test

Saab Gripen
4 Flight Tests
First single-engine, 100% renewable fuel
(FMV, GKN Aerospace U.S. Navy & Air Force)

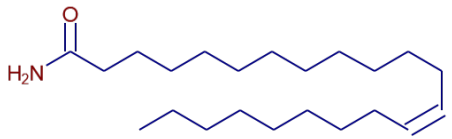
But why are the ARA Biofuels ISOCONVERSION (BIC) Process and Carinata Oil Such a Good Match?

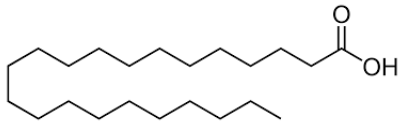
- Catalytic Hydrothermolysis (CH) includes a hydrothermal cleanup (HCU), which is a rapid hydrolysis and metals removal step
- HCU is 10-25 times faster than the Colgate-Emery fat splitting process
  - Results in the production of free fatty acids and glycerin-rich aqueous phase
  - The Glycerin-rich product can be concentrated into crude glycerin for use in animal feed or used as a feed stock to make other chemicals such as propylene glycol
- HCU is a very effective alternative to chemical degumming/metals reduction
  - Offers the potential to reduce oil production cost

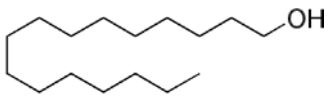
Metals (ppm)	Refined Carinata oil		Crude Peanut oil	
	Oil Feed	HCU Product	Oil Feed	HCU product
Calcium	4.3	1.2	25.6	4.0
Magnesium	3.0	0.4	28.0	0.9
Phosphorus	20.1	0.7	146.7	2.4
Potassium	6.7	2.2	67.5	2.8

Production of Clean Free Fatty Acids from Carinata Oil via the HCU Process

- Makes possible the recovery of erucic acid (22:1)
- Erucic acid has many direct uses that include lubricants
- Erucic acid is the precursor to many other products:
  - Eruciamide (75-80°C mp) – plastic films, plasticizer, lubricant, injection molding, textiles, paints
  - Behenic acid – hard wax (80°C mp) – cosmetics, candles, rubber, plastics, lubes, grease, coatings
  - Behenyl alcohol (80°C mp) – emollient, emulsifier, and thickener in cosmetics

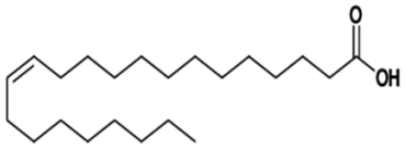




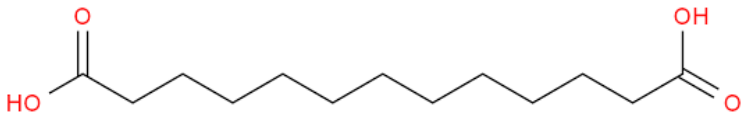


- Brassylic acid is a 13-carbon dicarboxylic acid derived from erucic acid via ozonation
  - Plasticizer for polymers, biodegradable solvents, lubricants, coatings, adhesives, fragrances, engineering plastics – nylon 1313, and other specialty polyamides

Erucic acid



Brassylic acid



Potential Market for Erucic Acid from Carinata oil

- High erucic acid rapeseed (HEAR) is another source of erucic acid
- ARA has been working with Emery Oleochemicals since 2014
  - Under the SPARC project ARA provided Emery clean FAAs from Carinata oil for testing and analysis (on-going)
  - A primary target market is the production of nylon 1313 from brassylic acid
- Emery projects this market could grow to 7000 MTY of erucic acid
  - This quantity would supply just the nylon 1313 market for one client
  - The value of FFAs from Carinata may be $0.60 to $0.80/lb depending on erucic acid concentration
  - The net revenue for a fuels production facility could exceed $10M/yr just to meet the requirement for one client
  - ARA is contacting other potential consumers as part of the SPARC project and developing a novel process to integrate erucic acid recovery with the HCU process
  - We are also working with a consultant who has more than 30 years experience in this industry and who recently retired from Proctor & Gamble

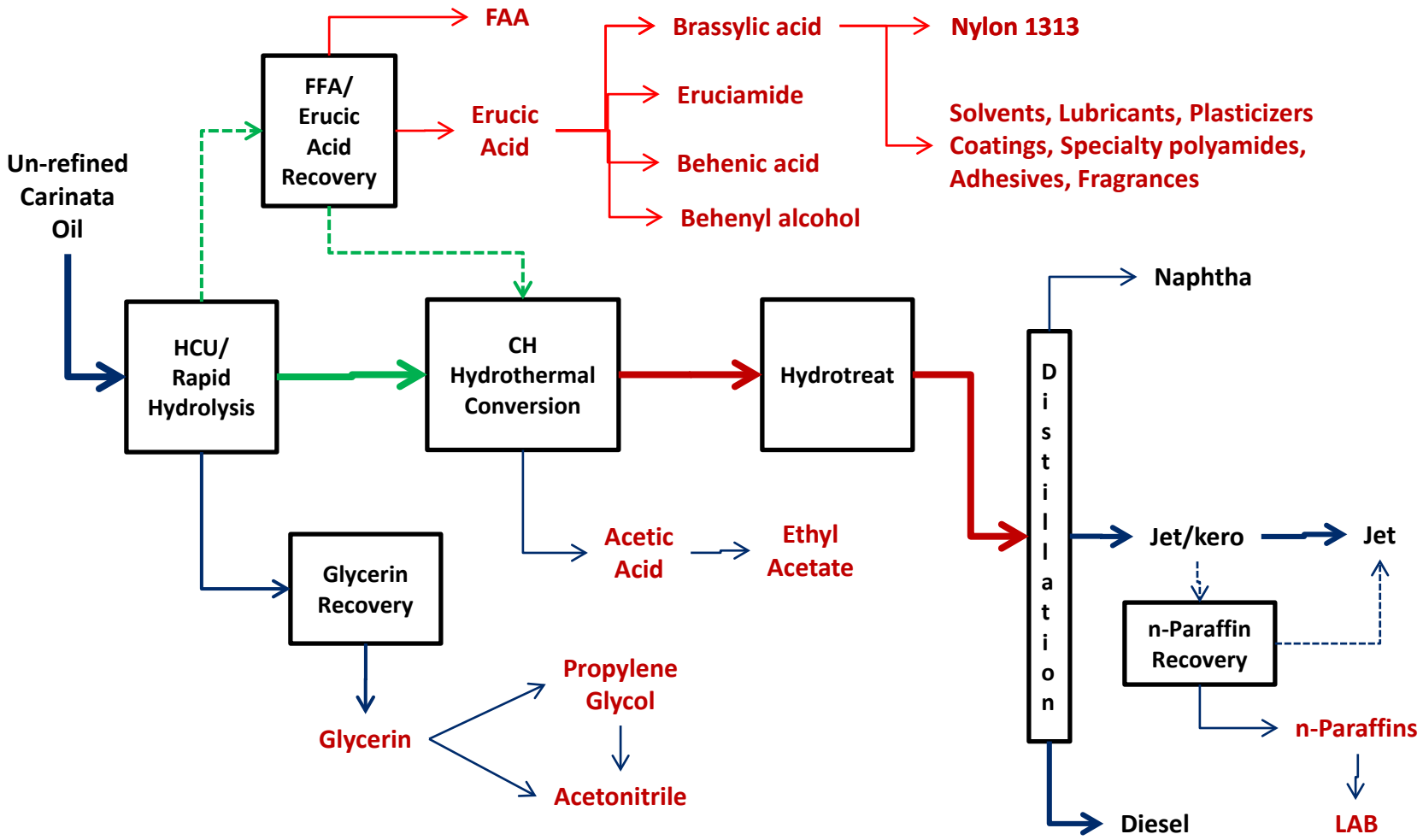
Fatty Acid Co-Product Market

- ARA & Agrisoma sponsored a "Feasibility Study for Oleochemistry Products from Brassica carinata" as part of a project sponsored by the state of Florida – UF prime
  - Performed by OBIC Bioproducts Innovation Center (Ohio State) – 2014
  - Identified co-product markets for erucic and behenic acid, erucamide, and behenyl alcohol
- ARA commissioned an "Analysis of the North American Oleochemicals Market"
  - Performed by Frost and Sullivan, 2016
  - A $3.9B industry (2018 projection) - Continued growth projected - ~25 active companies
    - Total volume is about 2 billion metric tons per year
  - Fatty acids account for 74% of market
  - Market leader (fatty acids) Emery Oleo – 21% share of the market
    - Other major players: Akzo Nobel – 13%, Vantage – 11%, Twin River – 7%, PMC – 7%, others – 41%
  - P&G is the market leader in fatty alcohols and glycerin (47% and 40% respectively)
  - Market applications include:
    - Soaps & detergents – 36%, industrial – 17%, personal care – 17%, plastics – 11%, food – 7%, coatings – 5%, rubber – 4%, pharmaceuticals – 3%

Normal Paraffin Co-product

- The BIC process produces a higher ratio of normal-to-iso paraffins than petroleum
- n-paraffins from the kerosene fraction are used to make linear alkyl benzene (LAB)
  - Soaps, detergents, surfactants
  - Global LAB market is huge – 4.3 million MTY and growing at 2.8% per year
- n-paraffins are produced commercially using molecular sieve extraction
  - Higher ratio of n-paraffins improves the economics of the extraction process
  - Higher value than kerosene achieved by improved efficiency and renewable premium
  - Extracting most of the n-paraffins from the jet fuel fraction will actually improve properties and increase the boiling distribution, which will offset yield loss
- ARA has work with Proctor & Gamble and Sasol since 2015 regarding renewable n-paraffins to make LAB for products like Tide detergent
- ARA provided P&G and Sasol samples for testing
  - n-paraffins must be very pure and kosher
  - Therefore the feed stock must be a virgin plant oil like Carinata

Production of Fuels and Co-products



ARA Tour

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