DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Drop-In Renewable Jet Fuel from Brown Grease via the Biofuels ISOCONVERSION™ Process

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System Development and Integration

Jeffrey Rine, Principal Investigator
Applied Research Associates, Inc.

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Project Overview

- "Drop-In Renewable Jet Fuel from Brown Grease via the Biofuels ISOCONVERSION™ (BIC) Process"
  - DE-EE0008506 was awarded 09/04/18
- Project goals
  - Clean up raw, low-cost, wet waste feed stocks (brown grease) from a variety of sources into an acceptable feedstock for conversion into jet fuel via the BIC process.
  - Demonstrate that the Hydrothermal Cleanup (HCU) process can economically reduce metals and phosphorus in brown grease and enable it to be converted into Jet and other renewable fuels at a mature price of ≤ $3 per GGE.

Project Overview

- Brown grease is a low-cost, wet waste feedstock that without significant pretreatment cannot be used in the production of renewable fuels due to high levels of contaminants
- The HCU process removes metals, phosphorus, and chlorine
- The clean brown grease is converted into jet fuel via Biofuels ISOCONVERSION (BIC)
- Catalytic Hydrothermolysis Jet (CHJ) produced by the BIC process was approved by ASTM as Annex 6 of D7566
  - Brown grease qualifies as a BIC feed stock in Annex 6
- Diesel fuel meets the ASTM D975 petroleum specification

Biofuels ISOCONVERSION (BIC) Process

Converts fats, oils, and greases into "drop-in" renewable fuels

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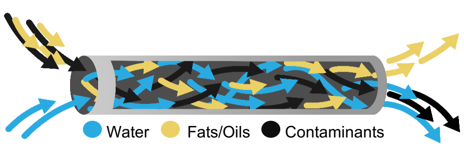
Hydrothermal Cleanup (HCU)

- Removes phosphorus and metals



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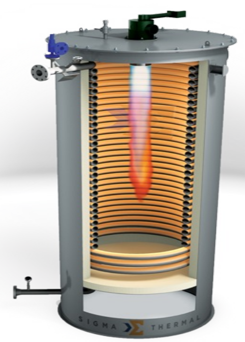
Catalytic Hydrothermolysis (CH)

- Supercritical water process
- Produces Syncrude with the same hydrocarbons as petroleum



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CLG
Chevron Lummus Global

Hydrotreating

- Saturates olefins
- Removes residual oxygenates

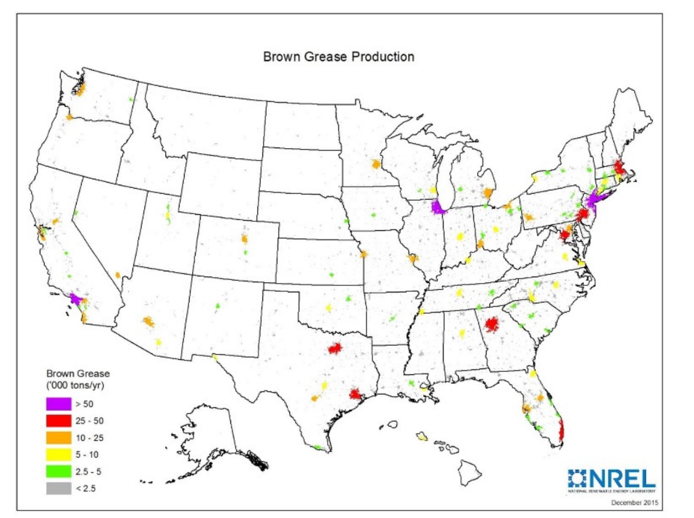
Distillation

- Produces Jet and diesel fuels that meet petroleum specs without blending

Conventional
Refinery Processes

Why Brown Grease?

- The majority of brown grease is disposed of in landfills and tipping fees must be paid
- If an economical cleanup technology for brown grease can be demonstrated, a large supply of brown grease could be aggregated in the U.S.
- Resource analysis performed by National Renewable Energy Lab (NREL) estimates 1.7 million tons of brown grease is produced each year in the United States, corresponding to 501 million GGE.



Approach – Primary Tasks

1. Initial verification
2. Identify, procure, and evaluate brown grease feedstocks
3. Perform screening tests on processing aids
4. Perform HCU optimization tests
5. Perform bench-scale CH conversion tests
6. Intermediate verification
7. Validate HCU performance at pilot scale
8. Produce clean brown grease from HCU
9. Validate CH performance at pilot scale
10. Produce CH syncrude from clean brown grease
11. Hydrotreat CH syncrude
12. Distill whole hydrotreated syncrude to produce spec jet fuel
13. Preliminary engineering for commercial system
14. Final verification

Key Technical Challenges

- Sourcing brown grease that has not be treated with lime
  - Eliminates the need to convert high amounts of calcium soaps
- Wide variability of brown grease properties
- Scaling in the HCU reactor caused by contaminants
  - Increases pressure drop, reduces cycle time between descaling
- Removal of contaminants to levels that permit further processing into renewable fuels
- Impact of high concentrations of nitrogen (protein) and sulfur in brown grease – Much higher than other FOGs
- CH conversion and hydrotreating into jet fuel that meets the D7566 spec - especially aromatic content (>8%)
- Sourcing appropriate size hydrotreating and distillation

Risk Mitigation Strategies

- Brown grease source requirements
  - Not neutralized or treated with lime – team with suppliers
  - Pre-treating to reduce protein content
  - Establish a nitrogen limit (<500-1000 ppm) if necessary
- Control CH conversion process to meet the D7566 spec
  - Increase conversion temperature to meet aromatic limit
- Identified Southwest Research Institute (SwRI)
  - Perform hydrotreating and distillation
- Adjust distillation cut temperatures to meet flash and freeze
- ARA performed pilot hydrotreating, distillation, and analyses to verify that syncrude produced by CH will meet D7566
  - Provided data to SwRI

Go/No-Go Decision Points

- Verification (Budget Period 1) Go / No-Go – *Complete*
- Verification (Budget Period 2) Go / No-Go – *Complete*

- Pilot Scale Production of Jet Fuel and Preliminary Engineering of Commercial System (Budget Period 3)
  - Production of Clean Brown Grease by HCU and Conversion by CH into >550 gallons of Syncrude – *Complete*
  - Hydrotreating of CH Syncrude at Southwest Research Institute (SwRI) – *Complete*
  - Distillation of Hydrotreated Products into Specification Jet Fuel at SwRI for Tier 1 and Tier 2 Testing – *In Progress*
  - Preliminary Engineering of Commercial System– *In Progress*

Hydrothermal Cleanup (HCU) Outcome

- Increasing the ratio of water-to-oil reduced reactor fouling rate and increased run time between clean-in-place events
- Pretreatment strategies to reduce protein content were not very effective

Typical HCU Product Contaminant Concentrations

Sample ID	Contaminants, mg/L						
	P	Ca	Mg	Na	K	Fe	N
Brown Grease Feed	7.00	0.6	0.01	0	0.8	106	1100
Clean HCU Product	0.2	0	0.01	0	0.6	6.9	775

CH Conversion Outcome

Properties of CH syncrude produced from clean brown grease

Property	Method	Results
TAN,mg KOH/g	D974	169
SG @ 60 ºF	D4502	0.8739
Bromine #, g Br_2/100 g	D1159	48
Chlorine, ppm	D7536	1.6
Phosphorus, ppm	D5185M	< 0.4
Total Metals, ppm	D5185M	< 2.0
Sulfur, ppm	D5453	164.47
Nitrogen, ppm	D4629	449.5
KF, % water	D6304	0.42

- Metals and phosphorus concentrations were reduced to levels well below requirements specified by commercial hydrotreating suppliers

Hydrotreating Outcome

- Hydrotreating was performed by SwRI in a two-stage configuration analogous to CLG commercial designs and use commercial catalyst
- Nitrogen and sulfur are easily hydrotreated without adversely affecting catalyst activity or performance

Properties of the whole hydrotreated liquid product

Property	Method	Results
TAN,mg KOH/g	D974	0.012
SG @ 60 °F	D4502	0.7806
Bromine #, g Br_2/100 g	D1159	0.4
Chlorine, ppm	D7536	< 1.0
Sulfur, ppm	D5453	5.67
Nitrogen, ppm	D4629	11.7

Yield Estimate from SwRI Hydrotreated Product

ASTM D2892 Physical Distillation Cut Temperatures and Yields

Fraction	Open Cut (°C)	Close Cut (°C)	Mass Yield (%)	Volume Yield (%)
Light Naphtha	-	74	6.1	7.2
Naphtha	74	130	13.0	14.3
Light Jet	130	140	1.5	1.5
Jet Main	140	249	25.5	25.4
Heavy Jet	249	265	3.9	3.8
Diesel main	265	343	39.0	37.9
Heavy Diesel	343	371	2.9	2.7
Residual	371	+	6.5	5.7
Loss			1.7	

Key Jet Fuel Properties

SwRI hydrotreated product distilled in accordance with ASTM D2892

Description	SwRI WHLP	CHJ Wide Cut	CHJ Narrow Cut	D7566 Jet A Spec
Cut Temperature, °C		130 - 265	135 - 260	
SG (60°F)	0.7806	0.7862	0.7858	0.775 - 0.840
Calc Cetane D4737		51.6	52.6	
API	48.75	48.48	48.57	
TAN	0.012	0.007	0.0109	0.015 max
Flash Point (°C)		39	45	38 min
Freeze Point (°C)		-39.5	-41	-40 max
Sulfur (ppm)	5.67	0.64	< 0.5	15 max
Nitrogen (ppm)	11.7	< 1.0	< 1.0	2 max
Aromatics (%m/m)		12.19	10.56	8.4 - 21.2
Aromatics (%v/v)		10.87	9.38	8.4 - 21.2
JFTOT D3241 @ 325 °C				
ASTM Code			1	< 3
Max Pressure Drop			0.100	25 max
Ellipsometer			20.76	85 max
Vol Yield (%, 60°F)		30.7	28.6	8.0 - 20.0
Mass Yield (%)		30.9	28.8	

Key Diesel Fuel Properties

SwRI hydrotreated product distilled in accordance with ASTM D2892

Property	Method	D975 Diesel Requirements	Diesel (max yield)	Diesel Blend Stock	Units
Cut Points	D2892		140 - 371°C	265 - 371°C	
Specific Gravity @ 60°F	D4052		0.8001	0.8085	
TAN	D974		0.0087	0.0086	mg KOH/g
Sulfur	D5453	Max 15	< 0.50	< 0.50	ppm
Flash Point	D56	Min 52	60	-	°C
Cloud Point	D2500		-1	11	°C
Pour Point	D97		0	12	°C
Cetane Index	D4737	Min 40	71.7	83.7	°C
Viscosity	D445	1.9-4.1	2.25	3.74	cSt
Aromatics	D5186				
Total		< 35	10.8	9.2	% m/m
Mono			10.4	8.4	% m/m
Di			0.4	0.7	% m/m
Distillation	D2887 converted to D86				
10%		Max 205	195	294	°C
50%			278	298	°C
90%		282-338	309	318	°C
FBP			331	338	°C

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2 – Progress and Outcomes – Milestones

Milestone 2.4: Brown Grease Characterized – Report to EERE detailing the characteristics of each brown grease procured.

Milestone 3.3.3: HCU Aids Evaluated Characterized – Report to EERE detailing the process impact of each aid evaluated

Milestone 4.3: Bench Scale HCU Testing Complete – Run report indicating product yields for each temperature and residence time tested.

Milestone 5.4: Bench Scale CH Testing Complete – Run report indicating product yields for each temperature and residence time tested.

Milestone 7.3: Initial HCU Pilot Test Complete – Comparison table indicating yields and product quality of pilot and bench tests.

Milestone 8.6: HCU Production Complete – 400+ gallons of clean Brown Grease

Milestone 10.5: CH Production Complete – 400+ gallons of "syncrude"

Milestone 12.6: Hydrotreater Campaign Complete – 400+ gallons of WHLP

Milestone 13.6: Distillation Campaign Complete – 100+ gallons of jet fuel. ***In Progress***

Milestone 14.4.5: Capital Cost Estimate Complete – DSCE (+/- 30%)

Milestone 14.5: Operating and Manufacturing Unit Cost Complete – Report to EERE with bottom line manufacturing cost per gallon of jet fuel produced

3 - Impact

- The use of brown grease to produce renewable fuels will:
  - Reduce waste going to landfills
  - Provide a very low-cost, low-CI feedstock for renewable fuels
  - Reduce the cost of sustainable aviation fuel (SAF)
  - Reduce the cost of renewable diesel fuel
- Patent
  - The HCU process was previously patented (US Patent # 10,071,322)
  - The CH process was previously patented (US Patent # 10,144,880 B2)
  - Additional patents are pending

Impact

- BIC Commercialization
  - The BIC process has been licensed to multiple parties
  - 3 licensees have completed front-end engineering (FEL-3)
  - 1 licensee is pursuing a USDA 9003 loan guarantee
  - Two commercial partners plan to use brown grease as a portion of their feed stock supply
- HCU commercialization
  - Three HCU systems, totaling more than 50,000 barrels-per-day, are under construction and will start up in 2023
  - Additional HCU licensees plan to use brown grease as a portion of their fat, oil and grease feed stock

Summary

- Brown grease is an underutilized, low-cost wet waste feedstock for renewable fuel production
- HCU reduces the contaminant levels in brown grease to levels acceptable for use in renewable fuels processes
- CH converts the cleaned up brown grease to syncrude that is hydrotreated and distilled into renewable fuels
- Jet fuel meeting ASTM D7566 Annex 6 specifications has been produced from 100% brown grease at pilot scale
- Work is currently in progress to produce 100 gallons of jet fuel meeting ASTM D7566 Annex 6 specifications from brown grease

Quad Chart Overview

Timeline
- Project start date: 01 October 2018
- Project end date: 31 March 2023

	FY23 Costed	Total Award
DOE Funding	$1,364,235	$2,360,000
Project Cost Share	$341,058	$591,431

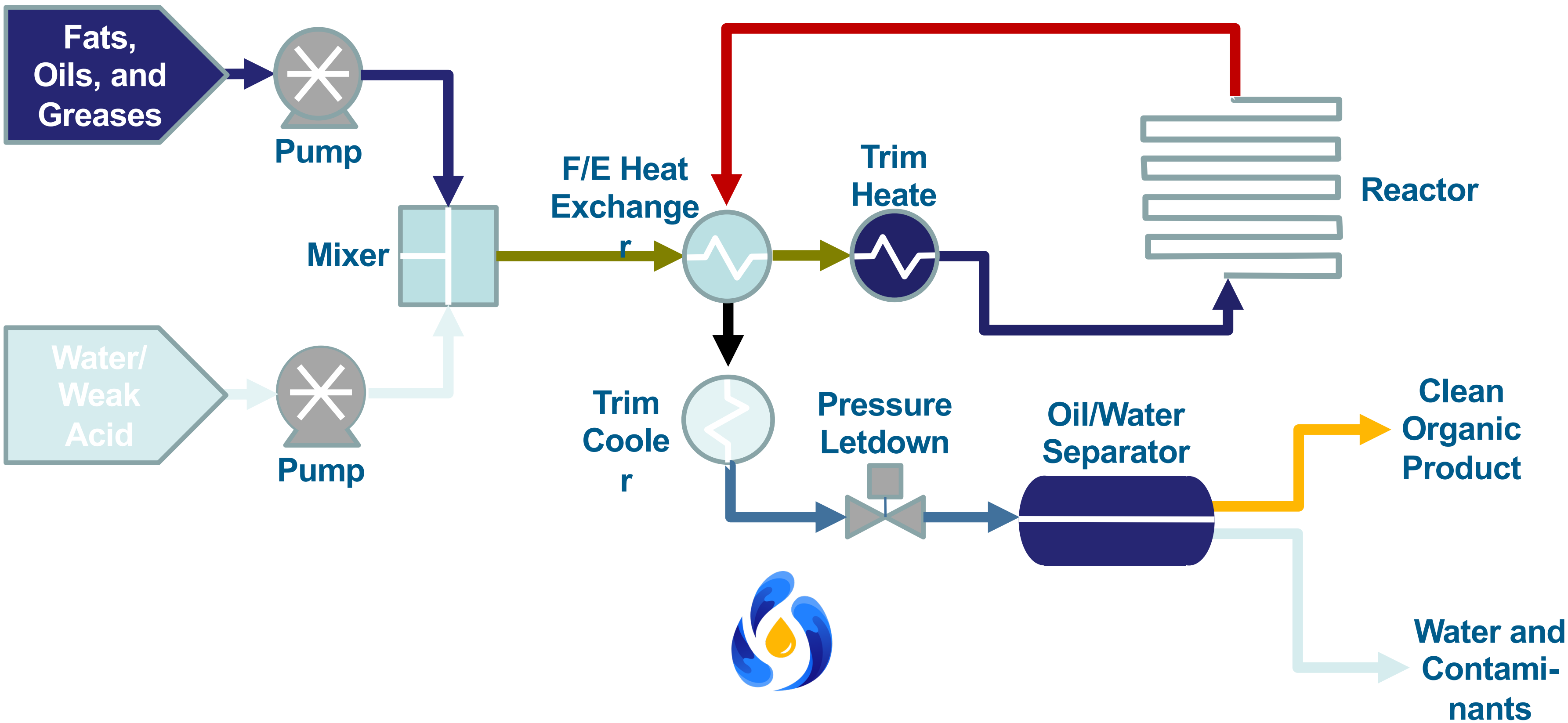
Project Partners
- Multiple licensees considering use of brown grease as a renewable feed stock

Project Goal
- Enhance the HCU process to convert raw, low-cost, wet waste feed stocks (brown grease) from a variety of sources into an acceptable feedstock for the CH process or other renewable fuel conversion technology.
- Demonstrate that the HCU process can be performed cost effectively on wet waste (brown grease) such that the resulting product(s) can be converted to renewable fuel at a mature price of $\leq$ $3 per GGE.

End of Project Milestone
- Produce 100+ gallons of jet fuel from brown grease.
- Complete preliminary engineering, including cost estimates on a commercial facility

Funding Mechanism
DE-FOA-0001926 2018
Topic Area 1: Drop-In Renewable Jet Fuel Blend stocks

Additional Slides



HCU PRETREAT

WATER. TEMPERATURE. PRESSURE. TURBULENT FLOW.

HCU Reactions

1. **Phospholipids/Gums:** Are hydrolyzed to form lipids retained in the organic product and phosphate salts in the effluent water
2. **Organic Chlorides:** Are hydrolyzed to form lipids retained in the organic product and chlorides in the effluent water
3. **Soaps:** Are acidulated to form free fatty acids retained in the organic product and salts in the effluent water
4. **Polyethylene:** Is depolymerized and retained in the organic product
5. **Inorganic Salts:** Are soluble in the effluent water