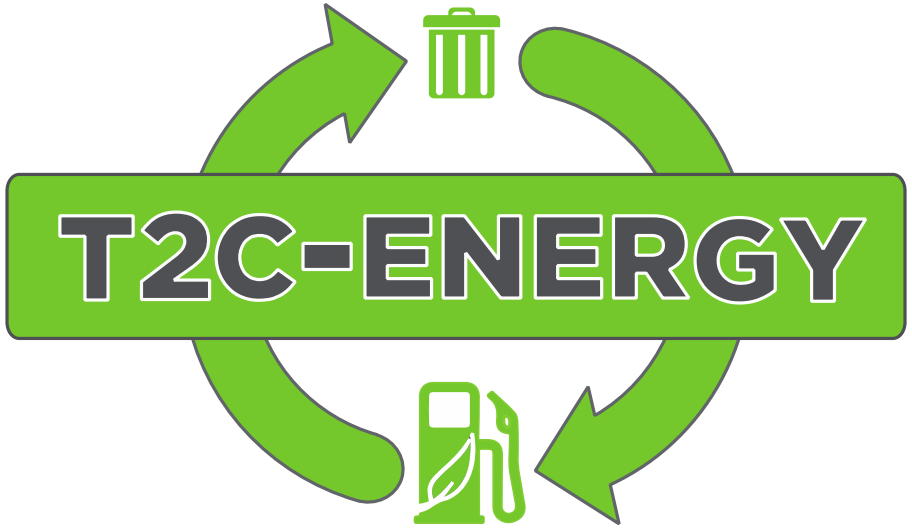
DOE BETO 2021 Project Peer Review



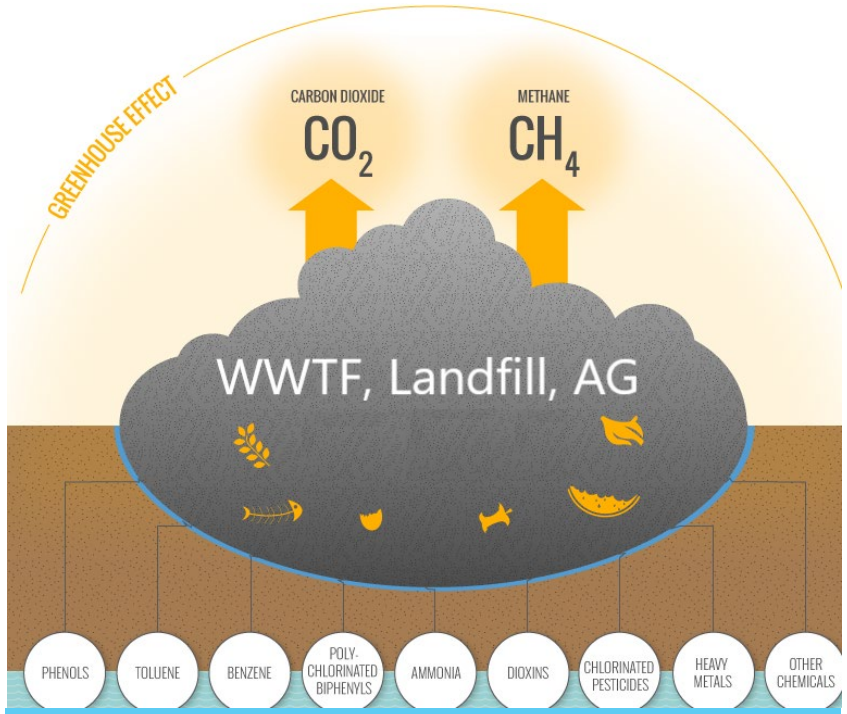
TRIFTS Catalytic Conversion of Biogas to Drop-in Renewable Diesel Fuel

March 26, 2021
Technology Area Session

PI: Devin Walker
Organization: T2C-Energy

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview



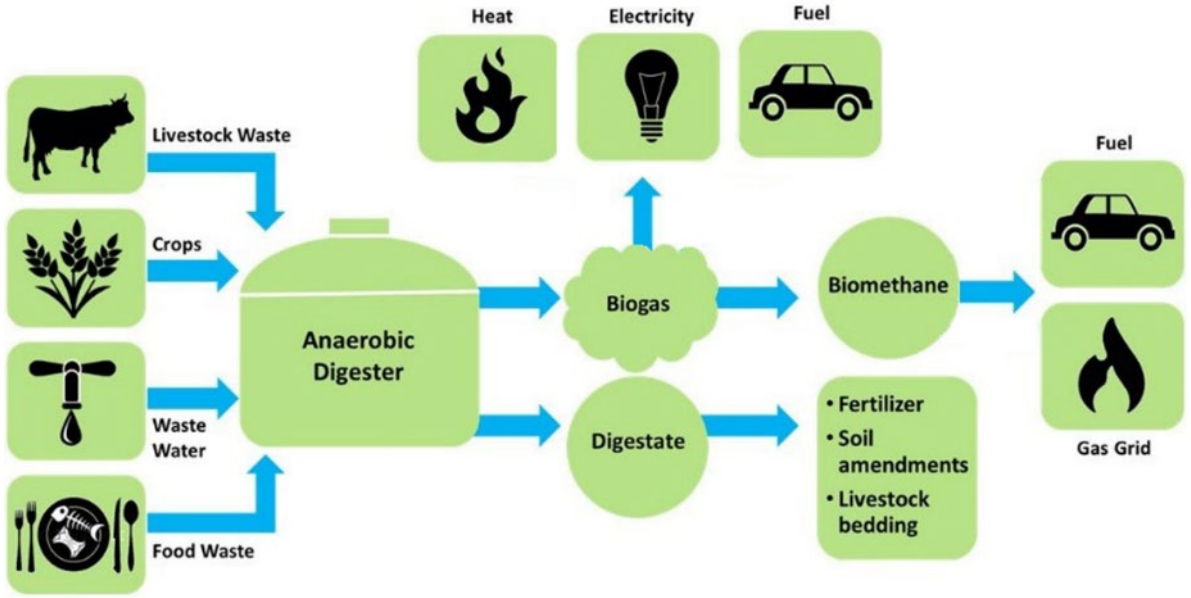
US: Biogas ~ 800,000 SCFM

Global: Biogas ~3,800,000 SCFM

2,450 Landfills & 1,500 Anaerobic Digestion (AD) Projects Operating in US

- Avg Size AD in US Produces ~210 SCFM Biogas
- Avg Size Landfill in US Produces ~1,380 SCFM Biogas
- Avg Natural Gas Processing Plant ~ 88,000 SCFM Biogas

What's the best use of this energy resource?



Key Factors

Economics

Location

Infrastructure

Efficiency

Policy

TRIFTS® Mobile Pilot Plant

PROJECT GOALS

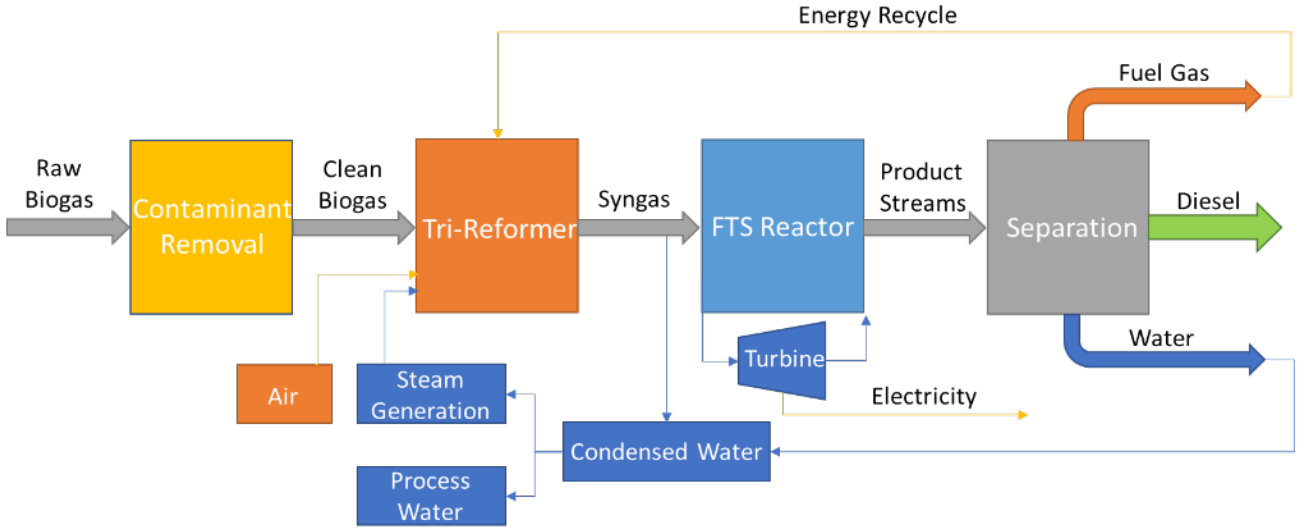
- Rigorously test pilot over broad range of biogas
- Optimize process design
- Produce drop-in cellulosic diesel meeting ASTM D975 spec
- De-risk technology at engineering scale (3rd party verification)
- Fuel pathway verification and carbon intensity (g CO2e/MJ Fuel)
- Detailed design and technoeconomic analysis of commercial scale plant

https://youtube.com/watch?v=GbioqF6G9Ow

Video Link

Unique Aspect Summary

- Maximize Biogas Feedstock Potential (CO_2 Utilization)
- Reduction of GTL Unit Operations
- Compatible with Current Infrastructure (Relevant Scale)
- Waste Derived Drop-In Diesel (Decarbonize Transport)
- Self Sufficient Process
- Produce D3/D7 RIN
- Attractive Economics and Profitability



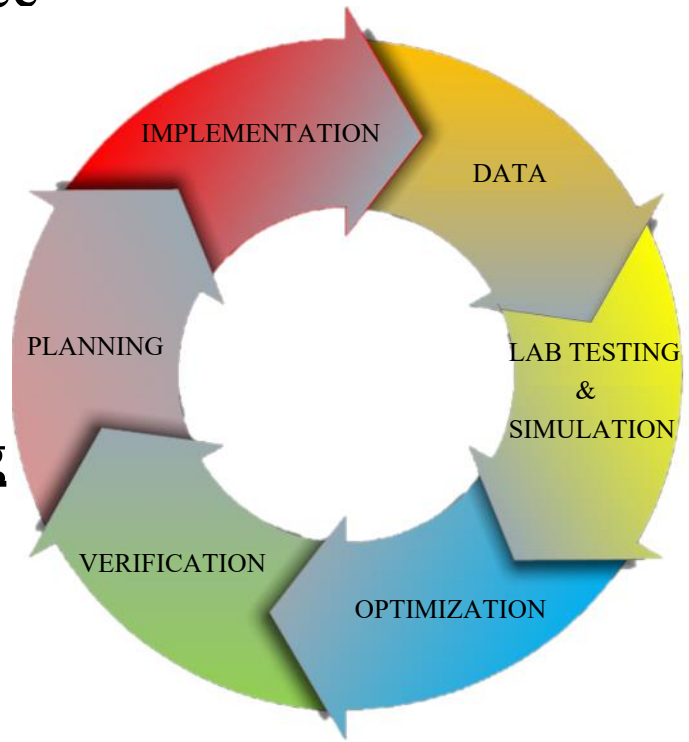
Management

T2C-Energy

- Pilot Operations
- Plant Modifications & Maintenance
- Pilot Data Analysis
- Catalyst Synthesis
- Lab & Pilot Data Integration
- Process Design Optimization

Third Party Engineering & Testing

- Pilot Performance Verification
- Detailed Engineering Design
- Total Installed Costs (CAPEX Validation)
- Fuel Testing & Registration
- RIN and LCFS Approval



University of South Florida

- Lab Testing (Catalyst & Contaminants)
- Modeling and Simulation
- Lab Data Analysis
- Literature Reviews
- TEA Verification

ARGONNE National Lab

- Data Analysis
- Life-Cycle Assessment
- GREET Model Development
- Verify Fuel Pathway

Management

Project Risk & Mitigation

Meet Process Performance Goals

- Gaps Identified During Demo
- Remedial Measures Made
- Strategies Developed, Modeled, & Tested
- Significant Design or Equipment Changes Reviewed (Cost/benefit justification)
- Process Design Improvements Modeled (COMSOL & HYSIS)

Operations & Safety

- Robust Standard Operating Procedures
- Environmental Management Control and Compliance
- Site Specific Safety Plans & Hazard Assessment
- Process Hazard Reviews

Process & Catalyst Longevity

- Long-term, Continuous Pilot Testing

Fuel Marketability

- Fuel Pathway Verification & Registration Assistance
- Fuel Policy & Price Reviews
- Long-term Off Take Agreements & Guaranteed Price

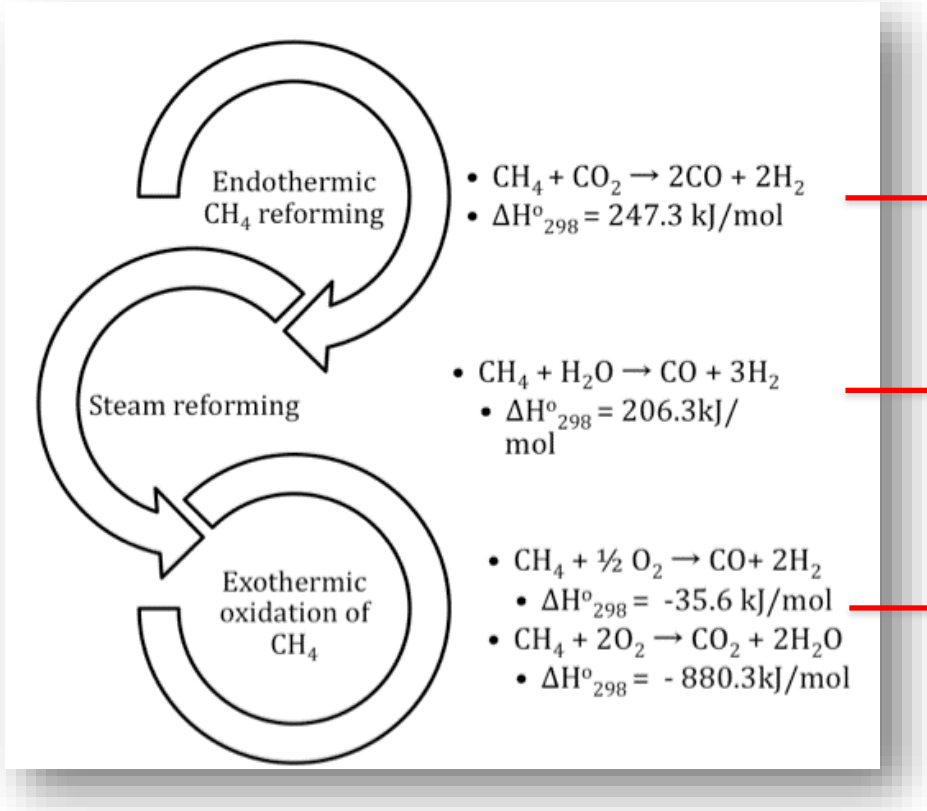
Process Economics & Funding

- Equipment Specs and Detailed Design
- Achieve MFSP < $3.00/GGE
- Stakeholder Engagement

Approach

Tri-reforming:

- Minimize cleanup and pretreatment process (**No CO_2 removal**)
- Less energy consumption
- Produce high quality syngas (H_2:CO ~ 2)



Utilize 100% of Biogas as Feedstock

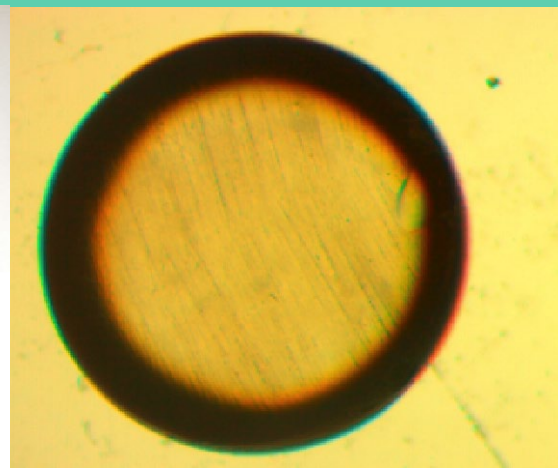
Control H2 and CO Selectivity

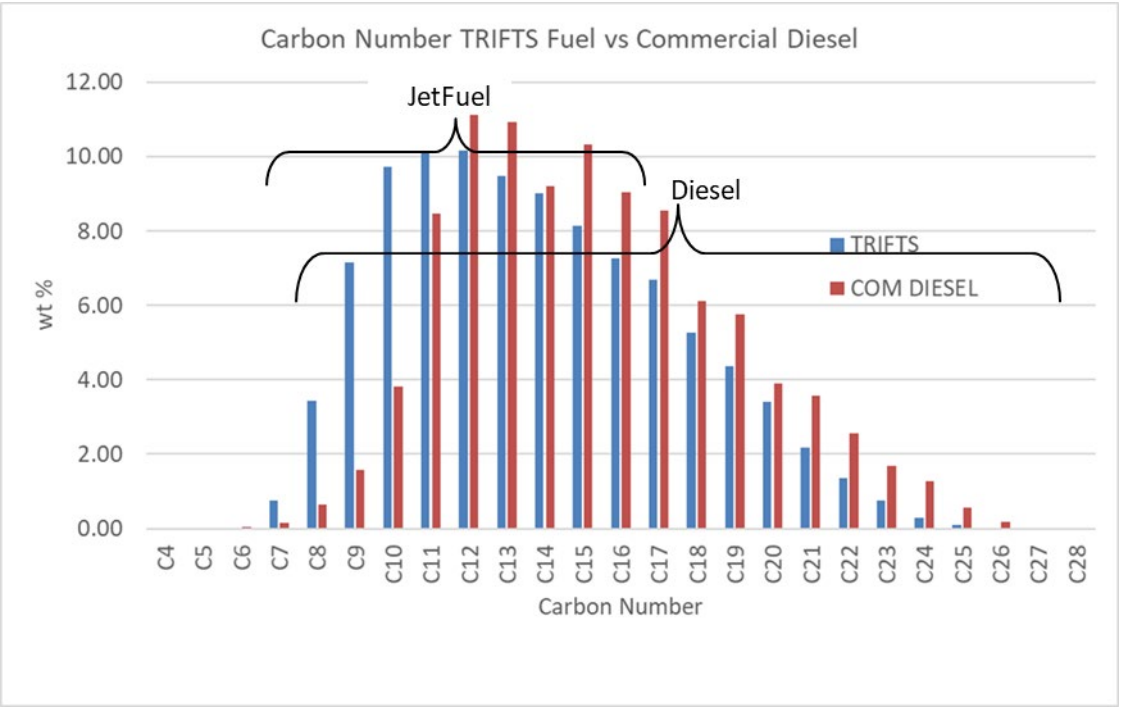
Generate Heat In-situ

Approach

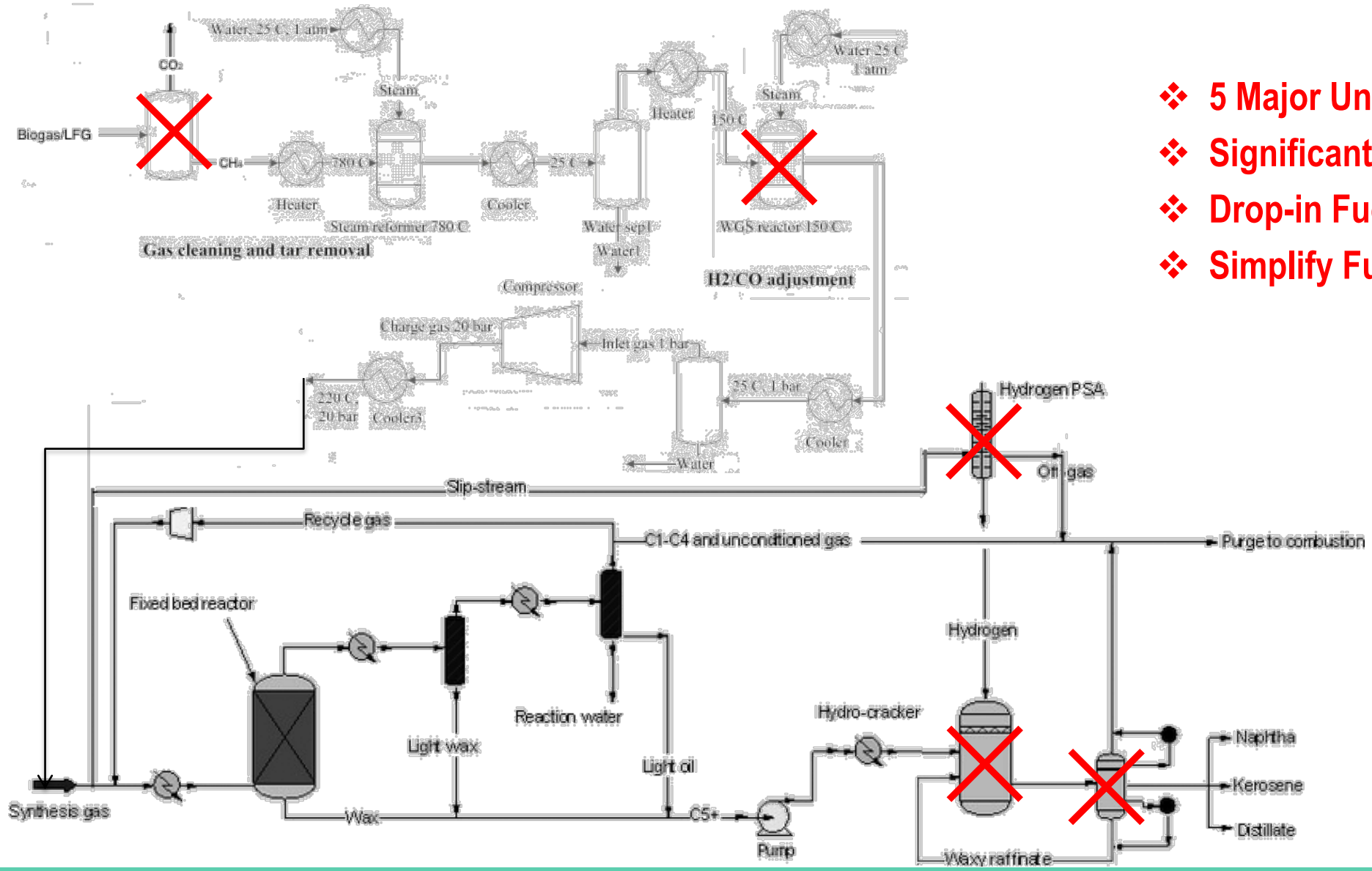
FTS Eggshell Catalyst

- Overcome heat and mass transfer limitations
- Tight temperature control throughout reactor
- Selective product distribution in middle distillate region
- Fuel product tunability
- Avoid wax production





Breaking the CAPEX/OPEX Barrier



- 5 Major Unit Operations Removed
- Significant CAPEX/OPEX Reduction
- Drop-in Fuel Out of FTS
- Simplify Fuel Distribution and Logistics

Approach

Challenges

- MYP Barriers ADO-D & ADO-F
- Cost Effective at Waste Industry Scales (Achieve MFSP of < $3.00/GGE) MYP Goal G20AD22
- Consistent production of in-spec diesel regardless of biogas source and over industrial relevant time periods
- Maintain high CO2 conversions while producing desired syngas quality and avoiding coke formation
- Achieve catalyst lifetimes > 6 months and On Stream Factor > 92%.

Approach

Period 1	**Go/No-Go Decision Point:** Initial DOE Verification (Completed March 2020)
Period 2	**Go/No-Go Decision Point**: Demonstrate Ability to Produce Drop-in Diesel Meeting ASTM D975 Fuel Specifications **Milestone:** Conduct pilot demo on-site biogas production facility **Milestone:** Produce diesel fuel for ASTM testing. **Milestone:** Recycle TRIFTS product water during pilot operations with no decrease (<1%) in conversions, product qualities, and efficiencies. **Milestone:** Verify heating and utility requirements are met by process outputs for self-sufficiency at steady state for full scale design. **Milestone:** Prove ability to produce drop-in fuels (per ASTM D975) without use of additional hydrocracking and/or hydrotreatment operations.
Period 3	**Go/No-Go Decision Point**: Achieve Over 100 hr Continuous Time On Stream and Produce Over 100 Gallons of Certifiable Diesel From Raw Biogas **Milestone:** Complete LCA and verification of GHG reduction. **Milestone:** Complete techno-economic analysis for both full scale facility and modular farm scale facility and prove MFSP of less than $3.00/GGE. **Milestone:** Obtain RIN credit approval.

Approach

Parameter/Performance	Description	Units	Benchmark	Intermediate Target	Final Target
Technology Readiness Level (TRL)	*Use TRL definitions provided in the TRL tab to describe the state of the proposed unit operation*	*TRL*	*6*	*7*	*7*
Scale for operations	*Raw Biogas Feed Rate to TRIFTS Pilot Plant*	*Biogas SCFM*	*9*	*12*	*24*
Contaminant Removal	*Removal of H2S below 10 ppm*	*ppm*	*3*	*0*	*0*
Residence Time	*Reformer*	*GHSV*	*12000*	*25000*	*30000 h-1*
Residence Time	*FTS*	*GHSV*	*2910 h-1*	*2910 h-1*	*2910 h-1*
Reformer Efficiency	*CH4 and CO2 conversion*	*mol conversions*	*CH4>81.6%, CO2>32.4%*	*CH4>90%, CO2>40%*	*CH4>90%, CO2>40%*
FTS Efficiency	*H2 and CO conversion*	*mol conversions*	*H2>64.95%, CO>57.02%*	*H2>70%, CO>60%*	*H2>80%, CO>70%*
H2:CO Ratio	*Syngas molar ratio (H2:CO)*	*mol*	*1.7-2.4*	*1.7-2.4*	*1.7-2.4*
Catalyst Lifetime	*Estimated or actual lifetime*	*hours*	*>2688 h*	*>4320 h*	*>4320 h*
Stability	*Hours on stream between regenerations*	*hours*	*336 h*	*672 h*	*1000 h*
Overall Liquid Yield	*Mass of liquidproduct/Mass of Feed*	*wt. %*	8.24%	10.41%	11.00%

- Contaminant removal < 10ppm
- Optimize regeneration cycles of media and catalyst
- Optimize ratio control of oxidants to achieve H_2:CO~1.7-2.4 and CO_2 conversions above 40%
- In-situ separations without distillation column (desired boiling points directly from process)
- Emulsion free liquid fuel product directly from process
- Fuel spec testing (ASTM D975)
- Recycle product water to process and measure effects
- Verify energy content of product gas exceed energy requirements of reformer and steam production (self sufficiency)

- Ability to generate sufficient electricity to power equipment & controls
- EPA fuel certification
- Complete GREET LCA model (AD and Landfill)
- Long term demo (>1000 hr)
- Verify commercial relevant catalyst lifetimes (>6 months)
- Independent 3rd party engineering assessment (verify nameplate and efficiencies)
- Finalize technoeconomic analysis (MFSP < $3.00/GGE)
- 3rd party diesel engine testing (secure fuel market / offtake)
- Fuel pathway approval for RIN and LCFS
- Design full scale facility

Impact

- Maximize Biogas Potential (Conversion of CO2 to Fuel)
  - 70% Increase in Convertible Portion of Biogas vs Current State of Art
- Waste feedstock (waste volume reduction pathway)
- Waste derived-cellulosic renewable diesel (energy dense fuel to decarbonize transport sector)
  - Only 55,892 D7 RIN generated in 2020
  - 459.7 MM D3 RIN generated in 2020
  - Unlocks 1.1 Billion D7 RIN Potential (fill the liquid fuel gap)
- Affordable Gas to Liquids Technology at Waste Industry Scale
- Dissemination of Results
  - Demonstrations Private & Municipal Level (Summary/Feasiblity Reports Distributed)
  - Two patents (US 10,144,878 and US 10,005,963)
  - WEFTEC 2020 Conference
  - WERF & WEF LIFT Presentation
  - Peer Review Papers
  - Graduate & Undergraduate Research Engagement

Impact

Private and Municipal Engagement

- Dairy Farm AD Demo (Trenton, FL)
- Citrus County Landfill Demo (Lecanto, FL)
- Pinellas County Water Reclamation Facility Demo (St. Petersburg, FL)
- Fuel Offtake Partners at Local and National Level
- Environmental Attribute Consultants
- Heavy Duty Engine Testing Facilities
- Specialty Chemical Manufactures
- Maritime Industry
- Waste Operators & Biogas Producers
- Renewable Energy Developers
- DEP & EPA (Permitting & Fuel Registration)
- EPC Firms

Progress and Outcomes

Initial Verification (Completed 03/31/20)

Milestone 1 (Completed 06/30/20): Conduct pilot demo on-site at landfill facility.

Milestone 2 (Ongoing expected completion date Mar 2021): Conduct pilot demo on-site at biogas production Wastewater AD facility.

Milestone 3 (Completed 05/31/20): Produce diesel fuel for ASTM testing.

Milestone 4 (Completed 05/31/20): Successfully recycle TRIFTS product water during pilot operations with little to no impact to product quality and efficiencies.

Milestone 5 (Ongoing expected completion date Jun 2021): Verify heating and utility requirements are met by process outputs for self-sufficiency during steady state for full-scale design.

Milestone 6/7 (Completed 05/31/20): Produce drop-in fuels (per ASTM D975) without hydrotreatment and/or hydrocracking operations.

Milestone 8 (Expected completion date Sep 2021): Intermediate DOE verification of project.

Milestone 9 (Ongoing expected completion date Mar 2022): Complete Life Cycle Analysis model and verification of Green House Gas reduction.

Milestone 10 (Ongoing expected completion date June 2022): Complete techno-economic analysis for Farm/AD/Landfill full scale facilities and prove MFSP of less than $3.00/Gasoline Gallon Equivalent.

Milestone 11 (Ongoing expected completion date Sep 2022): Obtain RIN credit approval.

Milestone 12 (Completed 06/30/20): Achieve over 100 hour of continuous time on stream to produce over 100 gallons of certifiable drop-in TRIFTS diesel fuel from raw (directly from waste facility biogas supply) biogas.

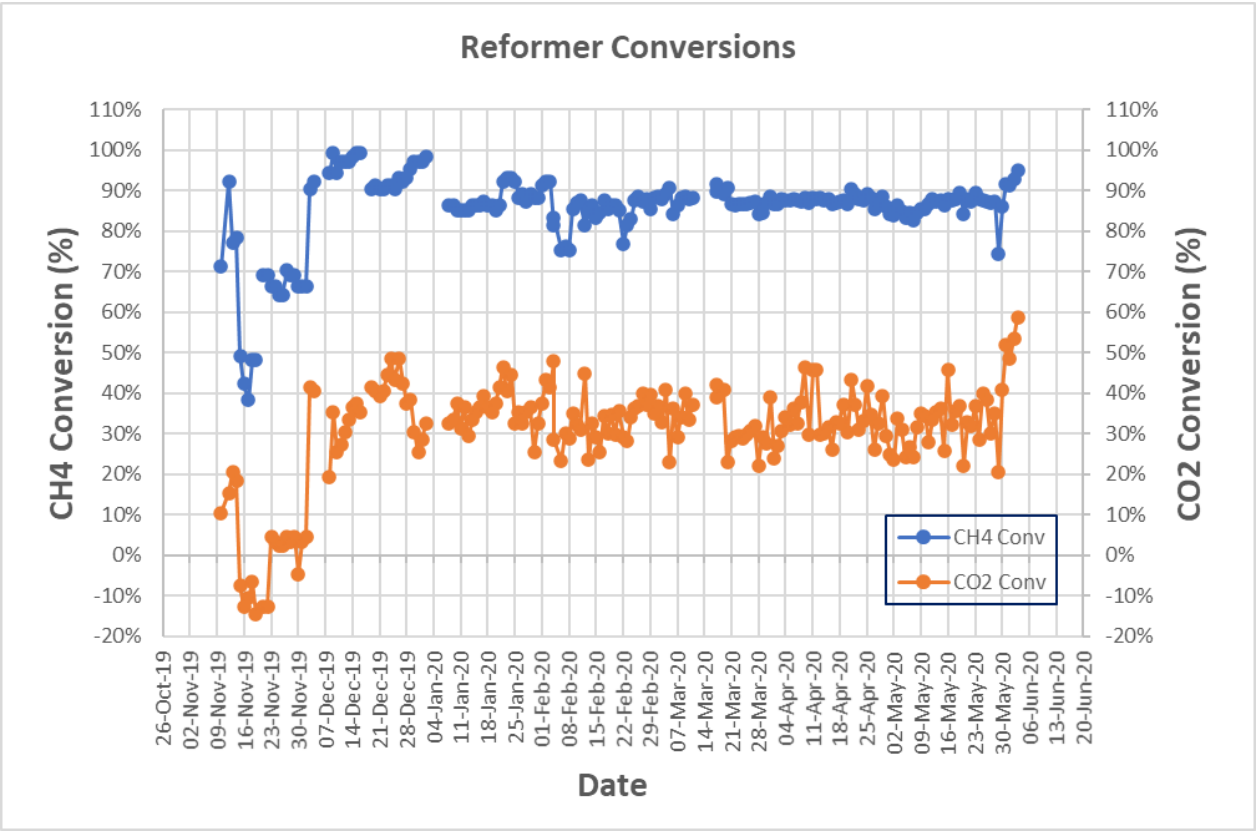
Milestone 13 (Expected completion date Dec 2022): Final verification of project.

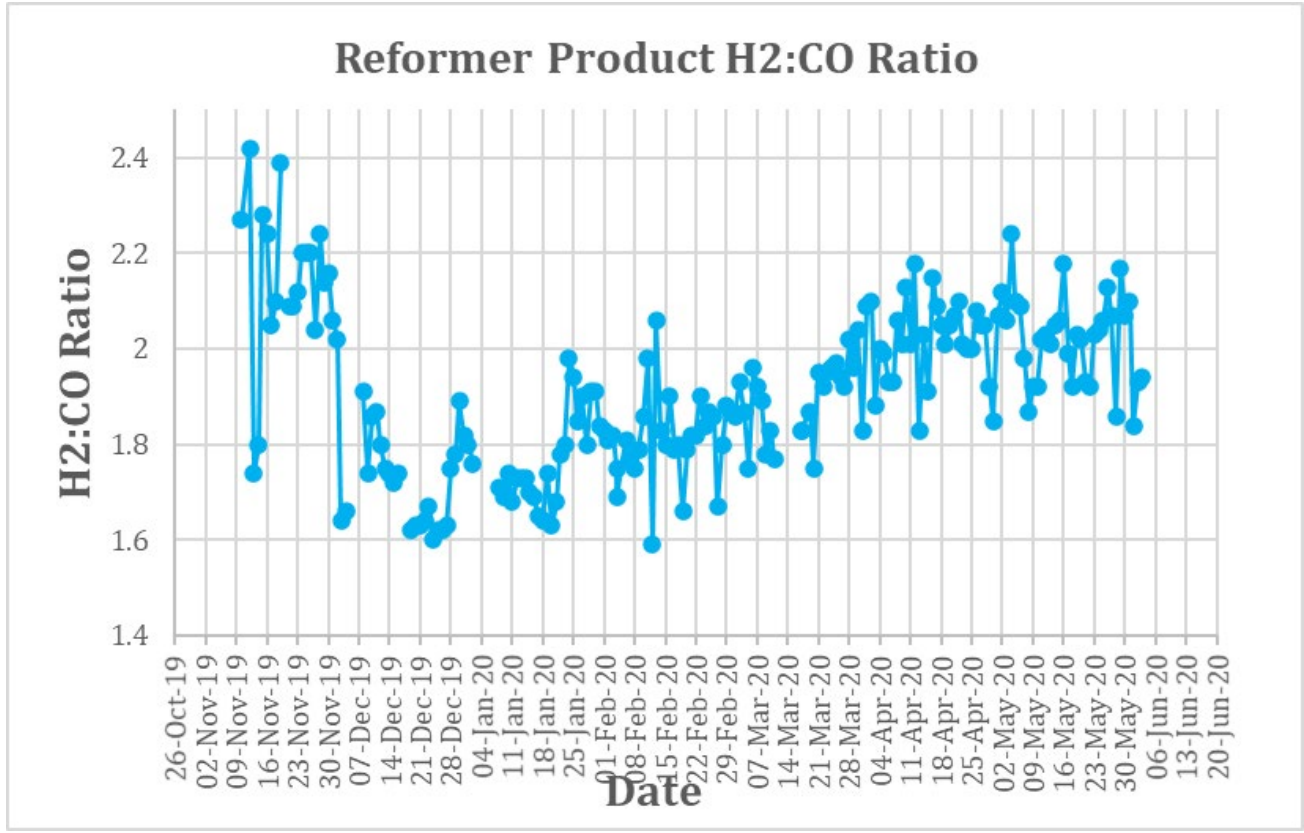
Progress and Outcomes

ASTM Method	EN Method	Lab Number	49673	TRIFTS DIESEL	Blend 27/73	Blend 27/73	ASTM D975		EN 590	
		Sample Code	Units	100% (neat)	Dairy/Com Diesel	Landfill/Com Diesel	min	max	min	max
D130 Fuels	EN ISO 2160	Copper		1A	1A	1A	-	No. 3	Class 1	Class 1
D2500	EN 23015	CloudPt	Deg C	-1	3	3	-	-	-	-
D2624	-	EConduct	pS/m	0	290	321	25	-	-	-
D2709	ISO 12937	TtlSmpl	Vol% (mg/kg)	< 0.005 (<50)	< 0.005 (<50)	< 0.005 (<50)	-	0.05	-	200 mg/kg
D4052	ISO 3675	Dens@15C	g/ml	0.7626	0.8245	0.8249	-	-	0.820	0.845
D445 40c	ISO 3104	Viscosty	cSt	1.792	2.321	2.347	1.9	4.1	2	4.5
D482	SO 6245	Ash	mass %	<0.001	<0.002	<0.003	-	0.01	-	0.01
D5186		TtlArom	Mass%	0.3	18.8	18.8	-	35	-	-
		MonoArom	Mass%	0.2	15.9	15.8	-	-	-	-
	EN 12916	PolyArom	Mass%	0.1	3.0	3.0	-	-	-	11
D524_10%	ISO 10370	RamsBott	wt%	0.04	0.05	0.06		0.35	-	0.3
D5453	ISO 20846	Sulfur	ppm	<0.5	5.96	5.89	-	15	-	10
D6079	ISO 12156-1	ASTM WSD	micron	340	330	340	-	520	-	460
D613	ISO 5165	CetaneNo		>75.3	55.6	53.6	40	-	51	-
D6217	EN12662	Ttl_Cont	mg/L (mg/kg)	1.2 (1.57)	1.6 (1.94)	1.9 (2.30)	-	-	-	24 mg/kg
D6371	EN 116	CFPP	Deg C	-4	-3	-3	-	-	-	0 (Grade B)
D6468_180	ISO 12205	Avg%Refl	%	100	99	99	80	-	-	25 g/m3
D86	ISO 3405	PCorrIBP	degF (°C)	316.9 (158.3)	318.9 (159.4)	328.6 (164.8)	-	-	-	-
		PCorrFBP	degF (°C)	616.1 (324.5)	670 (354.4)	669.2 (354)	-	-	-	-
		PCorrD10	degF (°C)	359.2 (181.8)	389.6 (198.7)	392.4 (200.2)	-	-	-	-
		PCorrD50	degF (°C)	455.9 (235.5)	491.9 (255.5)	493.9 (256.6)	-	-	-	-
		PCorrD60	degF (°C)	486.2 (252.3)	521.6 (272)	522.8 (272.7)		-	-	<65% @ 250C
		PCorrD90	degF (°C)	585.2 (307.3)	616.6 (324.8)	616.8 (324.9)	540 (282)	640 (338)	-	-
		PCorrD95	degF (°C)	605.7 (318.7)	645.8 (341)	647 (341.7)	-	-	-	680 (360)
D93	ISO 2719	FlashP-C	degC	59	57	63	-	-	> 55 C	-
D976	ISO 4264	CetanInd		73.4	53.3	53.4	40	-	46	-
	EN 14078	FAME	volume %	0.6	1.4	1.4		-	-	7

- 3rd Party Fuels Testing
- Landfill & Dairy Waste Derived Fuels
- Meet US and European Standards
- Cleaner Burning (Reduced SOx, NOx, and Particulates)
- Flexibility in Use and Distribution

Progress and Outcomes

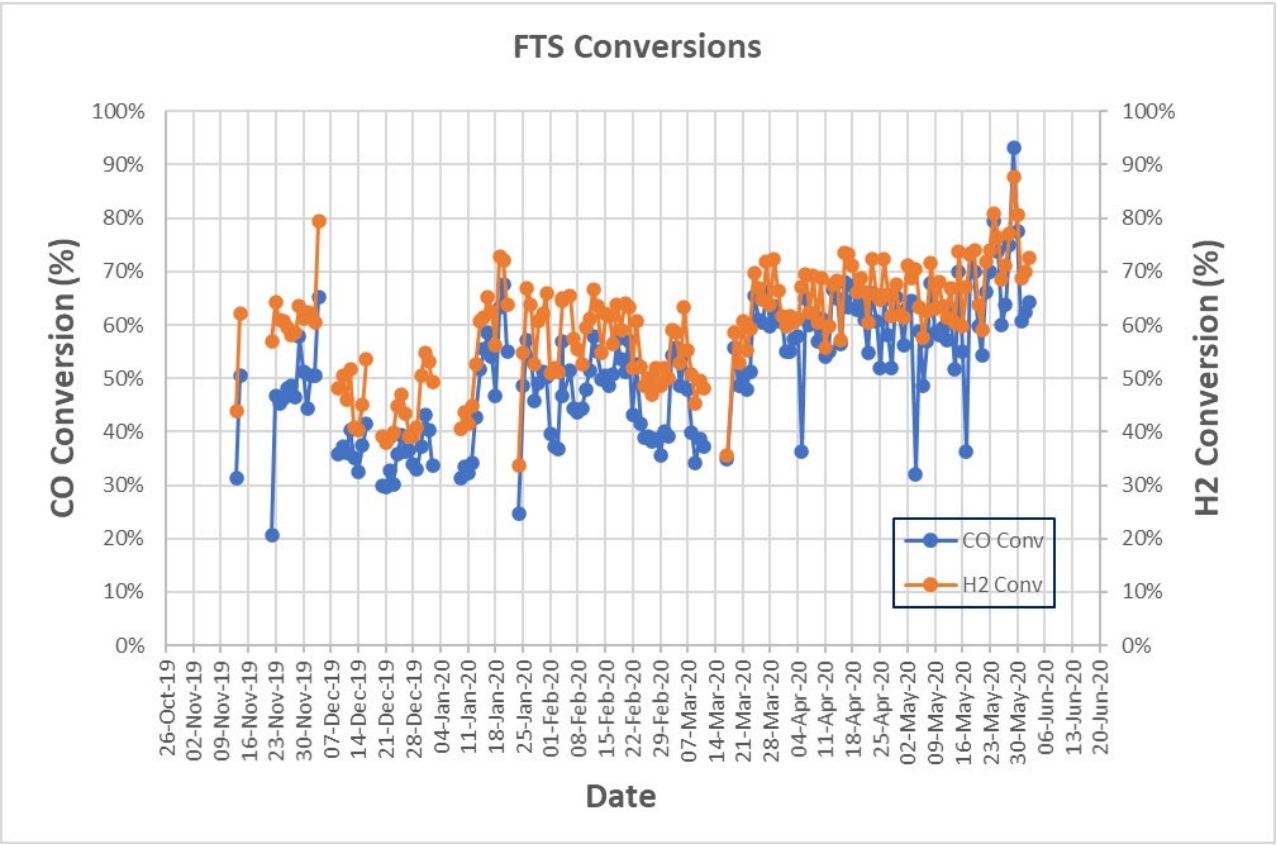


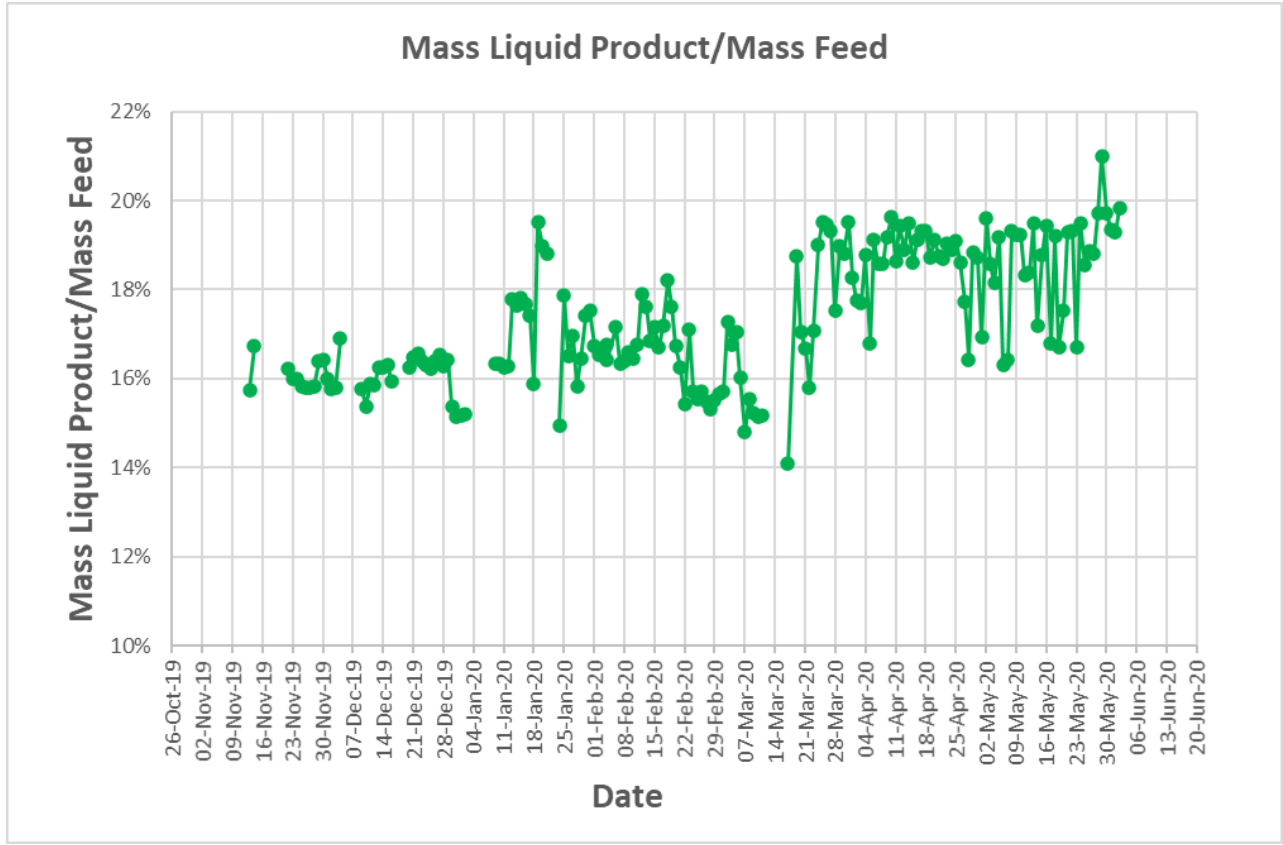


- CO_2 Conversion Key to Significant Fuel Yield Increase
- Steam and Air Influence CO_2 Conversion
- Short Circuiting Feed Contributed to Lower Conversions

- Ability to Control Syngas H_2:CO Ratios
- Syngas FTS Product Distribution Influence
- Expect Additional 10-20% Syngas Mass Yield Increase

Progress and Outcomes





- CO Conversion 50-70%
- No Permanent Loss of Activity after 7 Months
- Averaged 2 Months On Stream Between Regeneration

- Inert Feed Makes up ~50% of Mass
- Expect Additional 5-8% Fuel Yield Increase by End of Project

Progress and Outcomes

Primary Equipment Energy Balance (600 scfm Biogas Plant)		
	kWh Required	kWh Produced
Reformer	1,082	
Fuel Gas Energy Content		1,850
Waste Heat Boiler		1,559
Reformer Preheat	423	
Cooling Demand	919	
FT reactor		823
Biogas Compressor	44	
Air Compressor	28	
Syngas Compressor	233	
TOTALS		
Energy Required	2,729	
Energy Produced		4,232
Surplus Energy Available	1,502	

Self Sufficient (Energy Requirements Met)

- 1.5 MW available for Electric Generation
  - Steam Turbine ~ 360kWh Excess Electric
- Offload Anaerobic Digester Energy Requirements

Quad Chart Overview

Timeline

- October 1, 2019
- December 31, 2022

	FY20 Costed	Total Award
DOE Funding	$421,575	$2,177,758
Project Cost Share	$392,290	$651,953

Project Partners*

- University of South Florida
- ARGONNE National Lab

Project Goal

The goal of this project is to rigorously test T2C-Energy's mobile TRIFTS pilot plant to optimize catalytic parameters, process conditions, control schemes, mass and heat integration, economics, and environmental impact to design a universal gas to liquids platform capable of processing a broad range of biogas compositions into drop-in diesel fuel while remaining profitable at waste industry scales.

End of Project Milestone

Achieve over 100 hr of continuous time on stream to produce over 100 gallons of certifiable drop-in TRIFTS diesel fuel from raw biogas.

Funding Mechanism

DE-FOA-0002029 (2019)

Systems Research of Hydrocarbon Biofuel Technologies (AOI 4)

We Want to Hear From You

Sustainable Energy Solutions for The Waste Industry

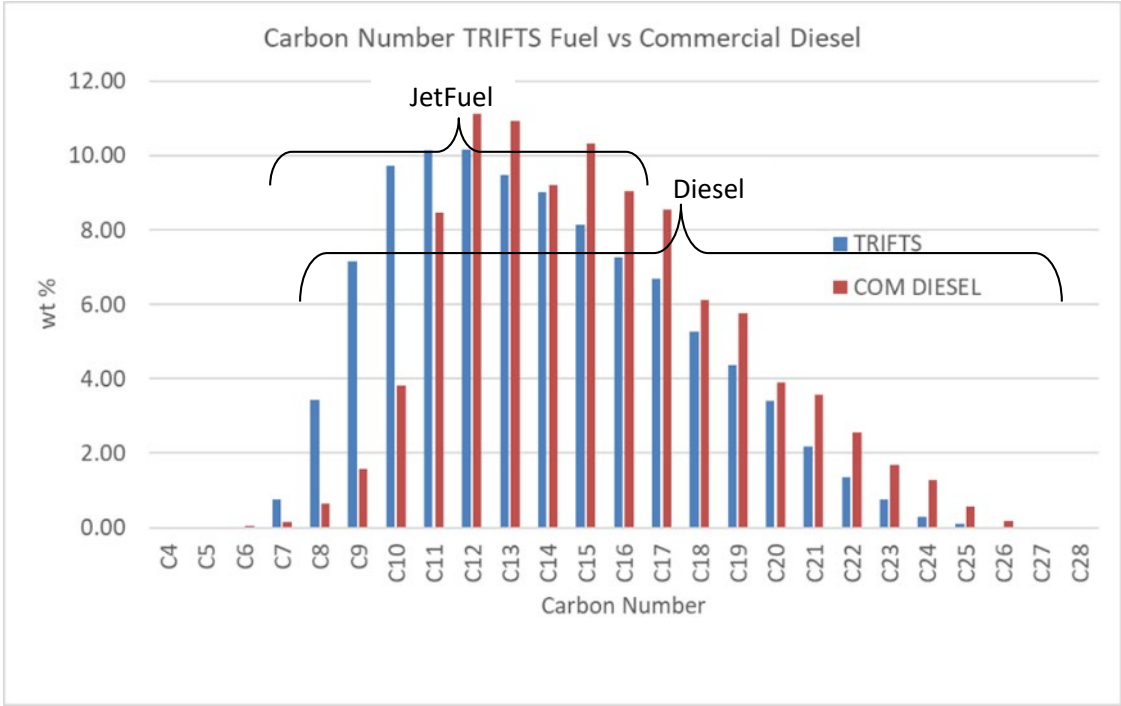
Contact Info
Email: dwalker@t2cenergy.com
Ph: 813-334-7332

TRIFTS® Fuel Analysis

Fuel Analysis

- 0 ppm Sulfur therefore zero SOx emissions
- Reduced Nox emissions
- Low aromatics reduces soot and particulates
- Isomers improve cold temp properties
- Excellent middle distillate boiling point distribution
- Final boiling point aligns with commercial diesel
- Meets ASTM D975 and EN590 specifications for No.2 ultra low sulfur diesel

Hydrocarbon Analysis Distribution (wt%)		
Compound	Commercial Diesel	T2C-E
n-paraffin	19.1	81.25
Iso-paraffin	30.2	16.44
Olefin	0.1	2.21
Cycloalkanes	9.5	0.1
Aldehyde	0.3	-
Alcohol	0.3	-
Alkyl Benzene	24.4	-
Indanes/Indenes	3.83	-
Napthalenes	8.27	-
Sulfur containing	0.01	-



Profitable Gas to Liquids Technology at Waste Industry Scales