DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

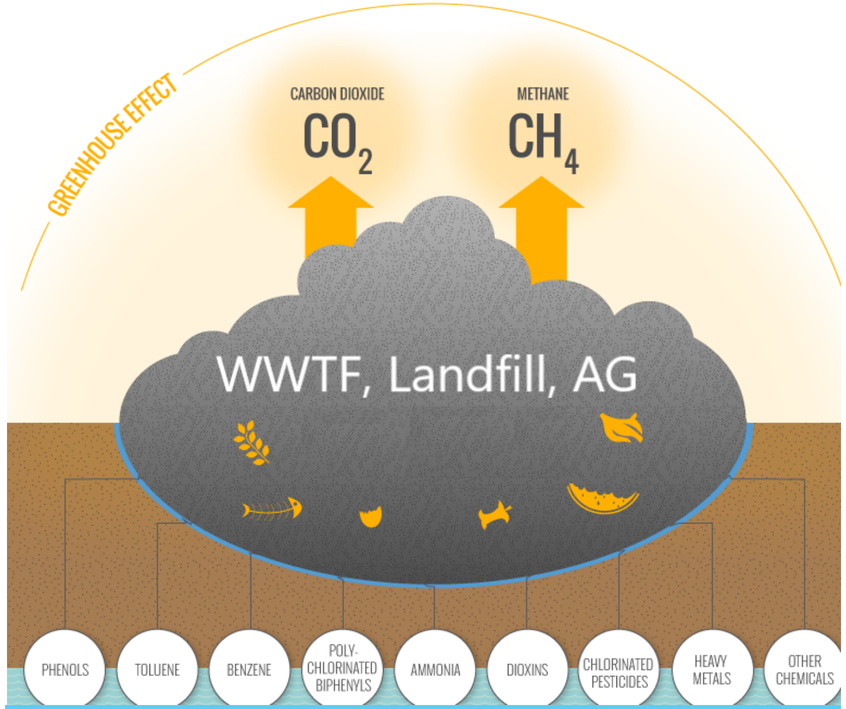
Demonstration Scale-up: TRIFTS Biogas to Renewable Fuel

WBS 3.5.3.105

April 3, 2023
Systems Development and Integration Session B

Principal Investigator: Devin Walker
Organization: T2C-Energy

Project Overview

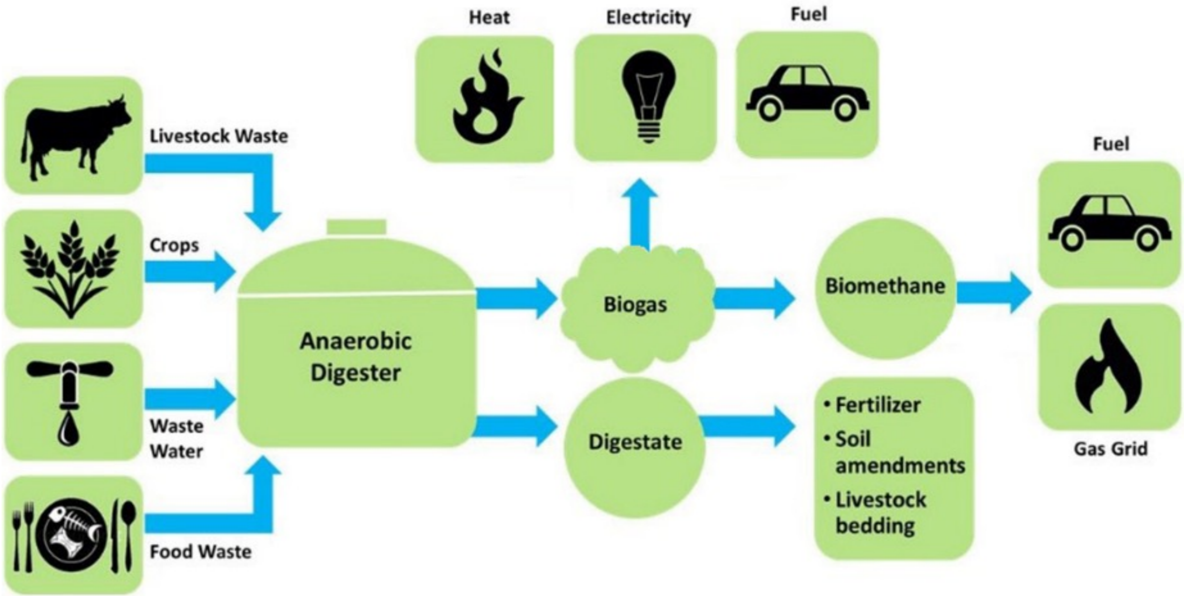


US: Biogas ~ 800,000 SCFM

Global: Biogas ~3,800,000 SCFM

- 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

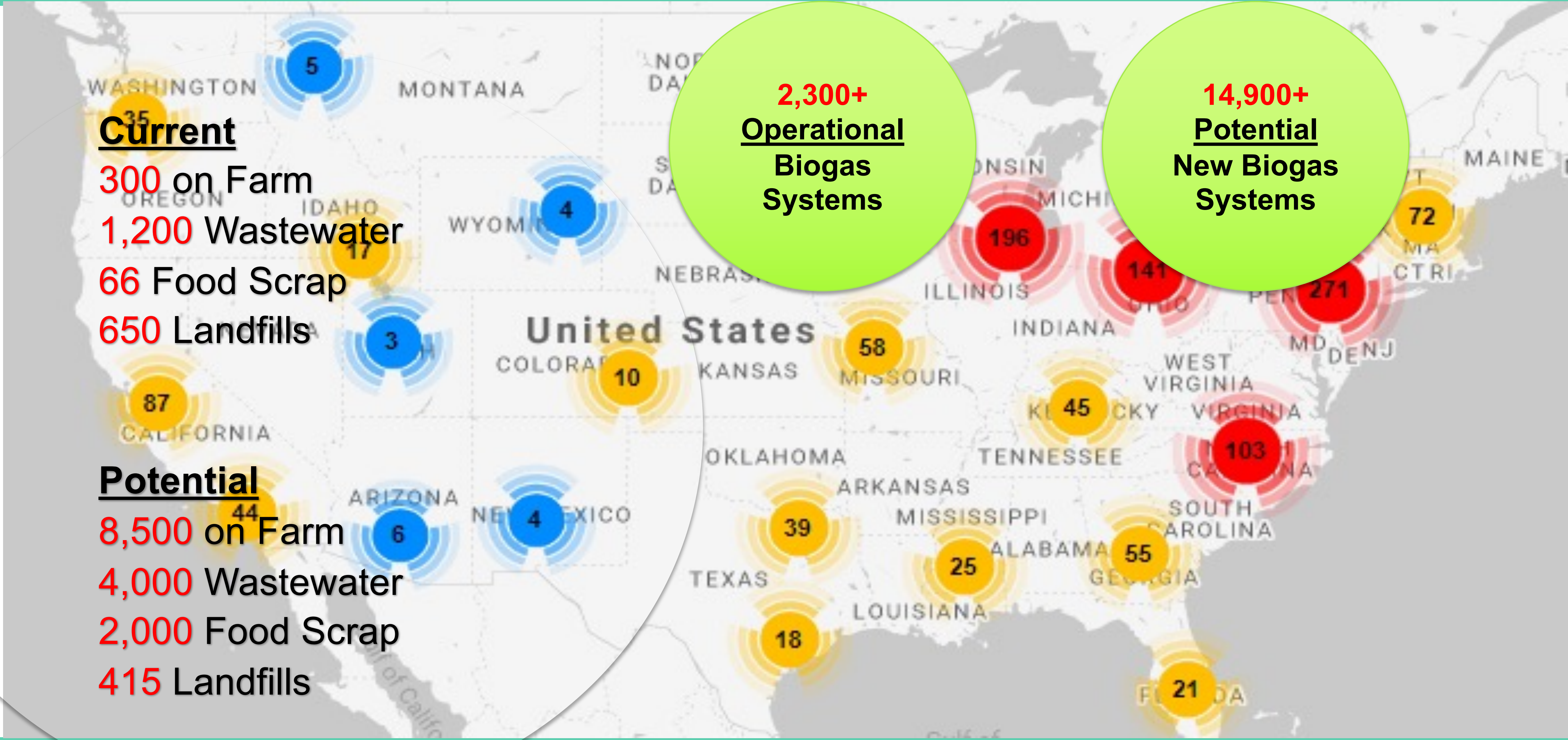
Infrastructure

Efficiency

Policy

Project Overview

T2C-ENERGY



Current

300 on Farm

1,200 Wastewater

66 Food Scrap

650 Landfills

Potential

8,500 on Farm

4,000 Wastewater

2,000 Food Scrap

415 Landfills

2,300+
Operational
Biogas
Systems

14,900+
Potential
New Biogas
Systems

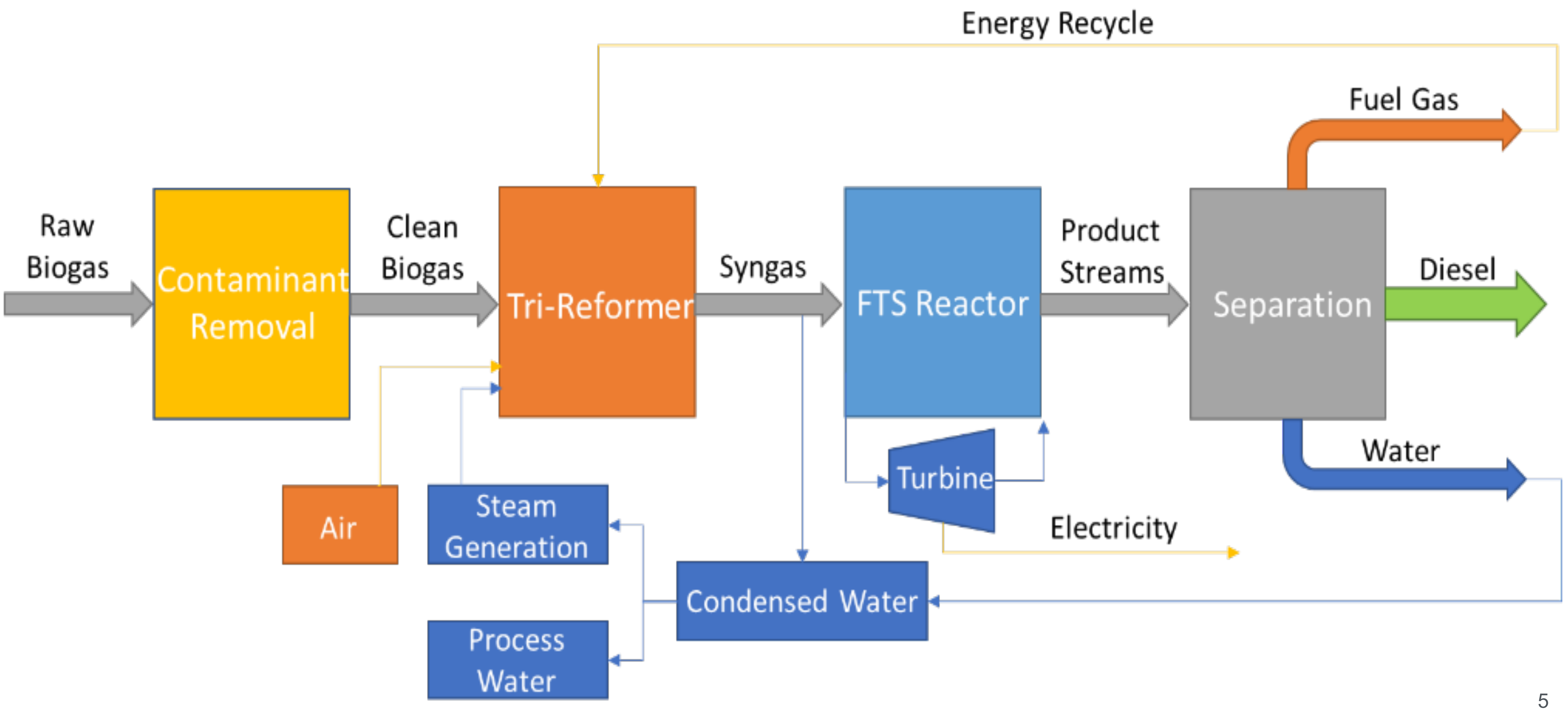
Project Overview

Goals

- Design first of a kind demonstration facility (~1,400 scfm)
- Construction and operation of landfill gas to diesel facility
- Produce over 1MM gal/year renewable diesel
- Minimum fuel selling price < $2.50/gal
- Greenhouse gas emission reduction > 70% vs petroleum

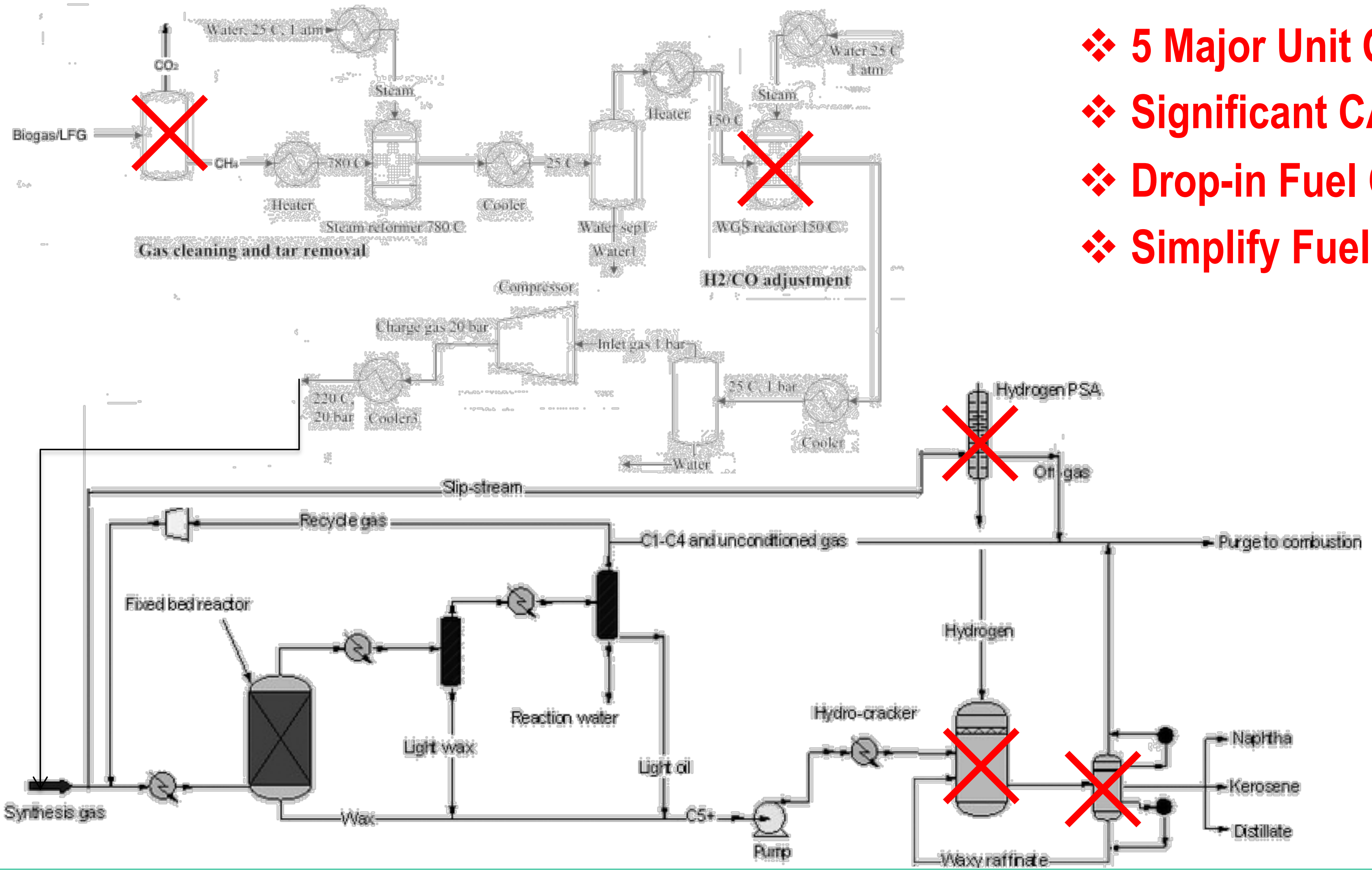
https://youtube.com/watch?v=GbioqF6G9Ow

Approach



Energy Recycle
Fuel Gas
Raw Biogas
Contaminant Removal
Clean Biogas
Tri-Reformer
Syngas
FTS Reactor
Product Streams
Separation
Diesel
Water
Air
Steam Generation
Turbine
Electricity
Condensed Water
Process Water

Approach

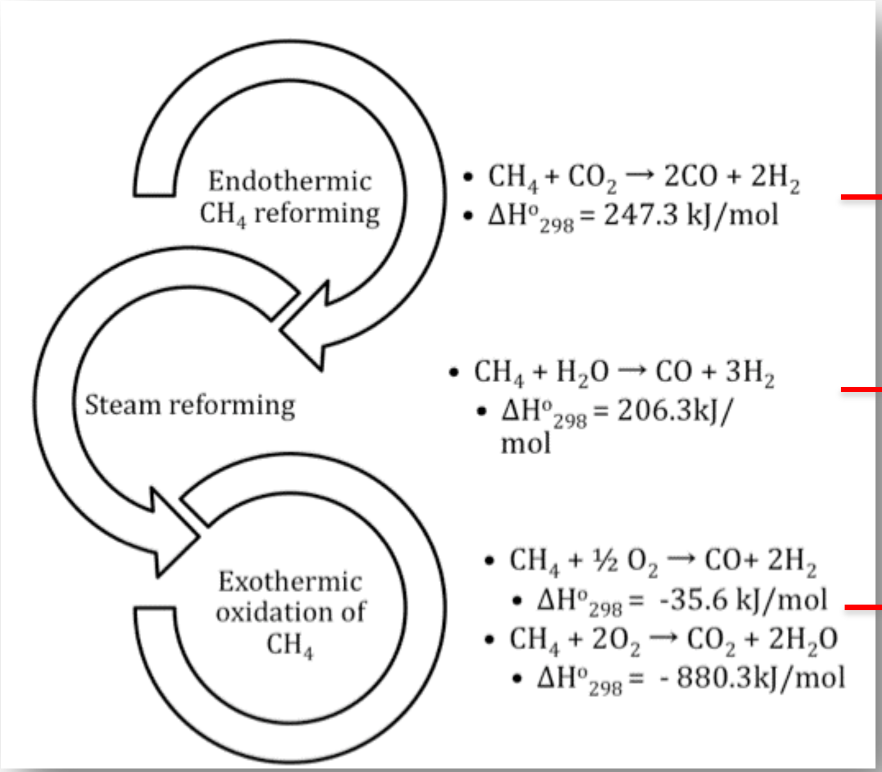


- 5 Major Unit Operations Removed
- Significant CAPEX/OPEX Reduction
- Drop-in Fuel Out of FTS
- Simplify Fuel Distribution and Logistics

Approach

<u>Tri-reforming:</u>

- 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

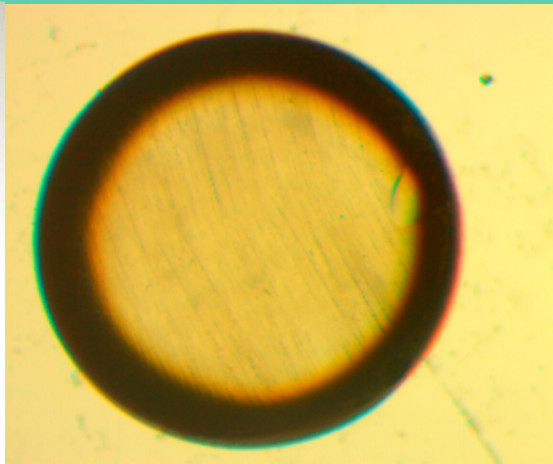
Control H2 and CO Selectivity

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
- In-situ Isomerization



TRIFTS Unique Aspects

- 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 and LCFS credits
- Attractive Economics and Profitability

Approach

<u>Challenges</u>

- MYP Barriers ADO-A, Ot-B, Ot-C
    - Process Integration
    - Cost of Production
    - Risk of Financing Large Scale Biorefineries
- Interactions of unit ops and long-term impacts
- Maintenance cycles
- Heat integration for self-sufficiency
- Cost friendly equipment at relevant scale
- Scalability of operational performance

Approach

Period 1 (Phase I)	**Go/No-Go Decision Point:** DOE Verification (Completed Oct 2021)
Period 2 (Phase I)	**Go/No-Go Decision Point**: Global Documents and Issue for Design package evaluation by DOE/Independent Engineers. Feedstock and offtake agreements approved.
Period 3 (Phase II)	**Go/No-Go Decision Point**: Issue for Construction package evaluation and approval to start construction.
Period 4 (Phase II)	**Go/No-Go Decision Point**: Complete construction and system verification. Commissioning plan approved for operations.
Period 5 (Phase II)	**Go/No-Go Decision Point**: Operation of demonstration facility meeting production capacity of 1MM gal/year renewable diesel with minimum fuel selling price of $2.50/gal and 70% greenhouse gas reduction relative to petroleum.

Approach

Risk Description	Consequence	Likelihood	Mitigation
Material and Supply Shortages	Schedule and cost overruns (3)	Possible (3)	Robust procurement strategy, communication with vendors, identification of long lead items, use of industrial standard equipment, market trend forecasting, stock and inventory management system.
Low Catalyst Performance	Low fuel production ,decreased revenues (4)	Unlikely (2)	Pilot and lab testing, effective regeneration cycles, early detection of deactivation and corrective action plan, well developed measurement system, well defined procedures and process setpoints.
Corrosion Issues	Increased O&M cost, equipment failure, plant downtime (3)	Possible (3)	Effective preventative maintenance schedule, early detection and inspections, corrosion resistant metals, lab accelerated corrosion studies
Biogas Supply/Quality Issues	Low fuel production, decreased revenues (3)	Unlikely (2)	Landfill gas collection and well system tuning, online gas analysis, automated ratio control of reformer feed, long term guaranteed biogas supply agreement
Process Integration Issues	Operational inefficiencies, increased OPEX cost, decreased revenues (4)	Unlikely (2)	Pilot testing, modeling and simulation, use of common industrial unit operations, industrial proven designs, experienced contractors and engineers, industry expert consultation, equipment and process specification list, factory acceptance testing, identification in design phase.
Operability and Reliability Issues	Low fuel production, plant downtime, operator safety (4)	Possible (3)	Clear administrative controls and operating procedures, monitoring of process, early alert alarm tracking, robust operations and maintenance training, equipment warranties, parts and labor warranties, preventative maintenance, industrial standard equipment, industrial proven unit operations, inventory management system, accurate measurement systems
Project Finance	High cost of capital (2)	Likely (4)	Proven performance at relevant scale, established project financing networks, experienced project partners, long term biogas supply and fuel offtake agreements, grant funding, refinance after 1st year of operations.
Team Capability	Slow project progress, cost overruns, project delays, milestones not met (4)	Unlikely (2)	Experienced EPC w/ previous GTL projects, industry expert consultants, owners engineer, wide range of relevant team expertise, previous project experience, familiarity with government contracting, familiarity with TRIFTS process.

Diversity, Equity, and Inclusion Plan

- Project Development within underserved rural communities
  - Index of Deep Disadvantaged Communities
  - STEM learning at elementary and high school levels
  - Public tours and presentations
- Inclusion of underrepresented groups as employees, researchers, and interns
  - Woman, Hispanic, and Veteran Staff
  - Support University of South Florida URM/REU/RET programs for underrepresented minorities
- Thoughtful and deliberate integration of diversity into everyday practice
- Implicit bias training for existing and new staff
- Utilize minority, woman, and veteran owned businesses as vendors and contractors
  - URM > 25%
- Local disadvantaged businesses utilized during construction and operational phases
- Collaboration with American Indian Tribes (waste to energy strategy development)

Progress and Outcomes

- **Verification completed by DOE/IE confirmation of TRL 6**
- **Performance validated: Reformer and FTS efficiencies and conversions meet project objectives**
- **Proforma Capex validated: AACE class 3-4**
- **TRIFTS process recognized to meet DOE BETO GPRA milestone of validating a biofuel pathway at engineering scale with a price of less the $3 per gasoline gallon equivalent and with at least a 60% reduction in greenhouse gas emissions.**
- **Independent Engineers validated TRIFTS process at MFSP of $2.91/GGE and GHG reduction of 130% without government subsides or credits.**

Table 1
Overview of Verification Test Data

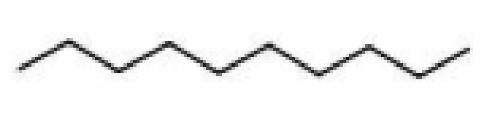
Unit Operation	Key Performance Parameter	Red Flags	Anything Lacking?	Readiness to Proceed	Path Forward
Overall capacity of system to process biogas	Biogas Flow Rate	None	Nothing Noted	Yes	Proceed with BP2 activities
Biogas decontamination	Reduction of H_2S and removal of siloxanes	None	Nothing Noted	Yes	Proceed with BP2 activities
Reformer	Conversion efficiency	None	Nothing noted	Yes	Proceed with BP2 activities
Reformer	H_2 to CO molar ratio	None	Nothing noted	Yes	Proceed with BP2 activities
Fischer Tropsch Synthesis	Conversion efficiency	None	Nothing noted	Yes	Proceed with BP2 activities
Fischer Tropsch Synthesis	Overall liquid yield	None	Nothing noted	Yes	Proceed with BP2 activities

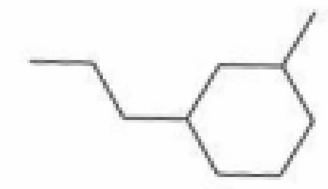
[Department of Energy's Bioenergy Office Achieves Major Biofuel Technology and Production Milestone | Department of Energy]

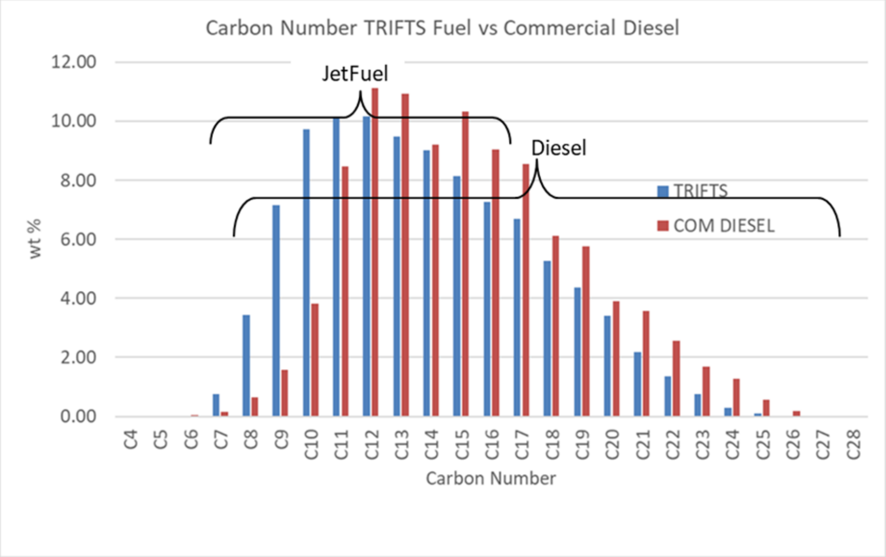
Progress and Outcomes

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



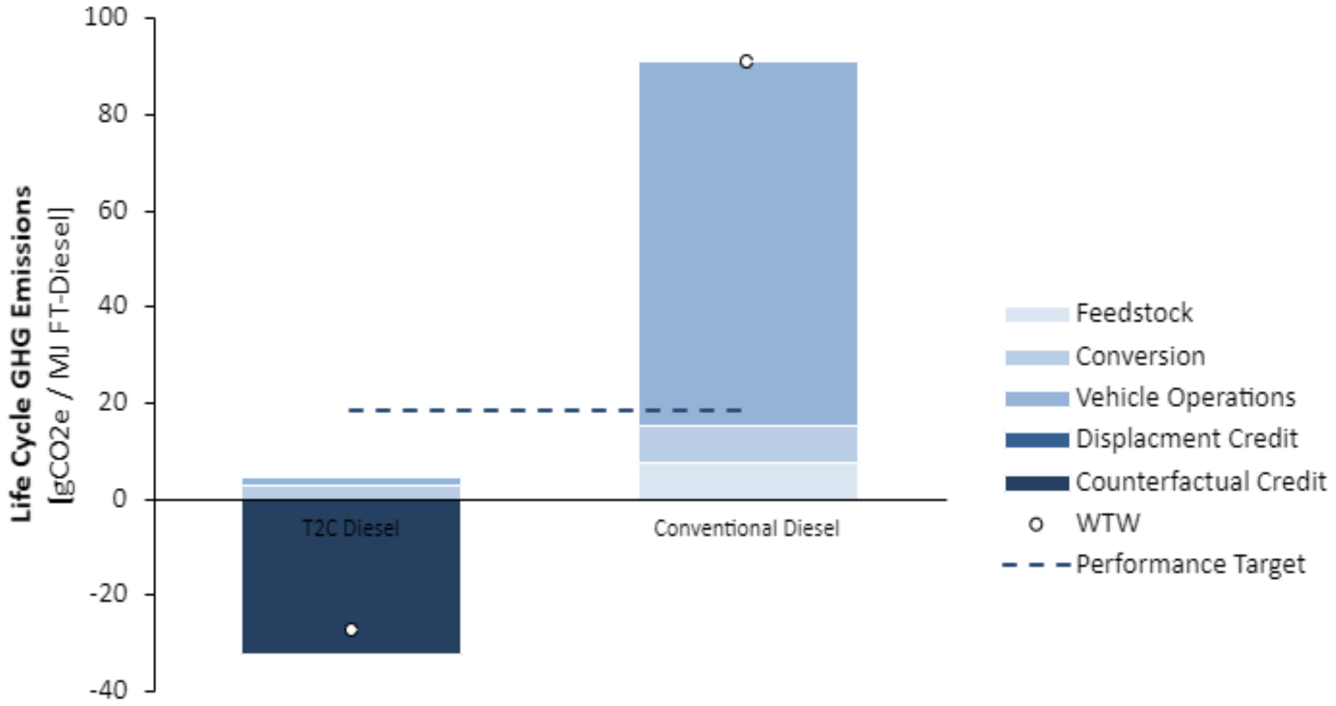




Progress and Outcomes

- HYSIS fully integrated with heat and mass recycle
- Biogas composition impacts (reactant feed auto tuning)
- ANL GREET model updated with TRIFTS Life Cycle Analysis
- Basic engineering design package (Global Docs completed)
  - Heat and mass balances
  - PFD's
  - General arrangement
  - P&ID's
  - Equipment / Instrument spec list
  - Control architecture
  - Pipe sizing and metallurgy study
- Engineering package Issued for Bids

ANL GREET Model Carbon Intensity Score



Landfill Application CI ~ - 36gCO2e/MJ

Progress and Outcomes

Energy Balance

- Reformer energy requirement provided by FTS fuel gas
- Efficient heat integration
- Utility requirements provided by process itself
- Overall self sufficient process
- Minimize any outside fossil fuel derived energy inputs
- Carbon Intensity ~ 80 gCO2e/MJ lower than RNG

Plant Electricity Use/Production (1,400 scfm Landfill Gas)	kW
Compressors	865
Chiller	91
Cooling Tower	72
Pumps	22
Trim Heaters	60
Total Parasitic Load	1110
Turbine Electrical Output	1261
Excess to Grid	151

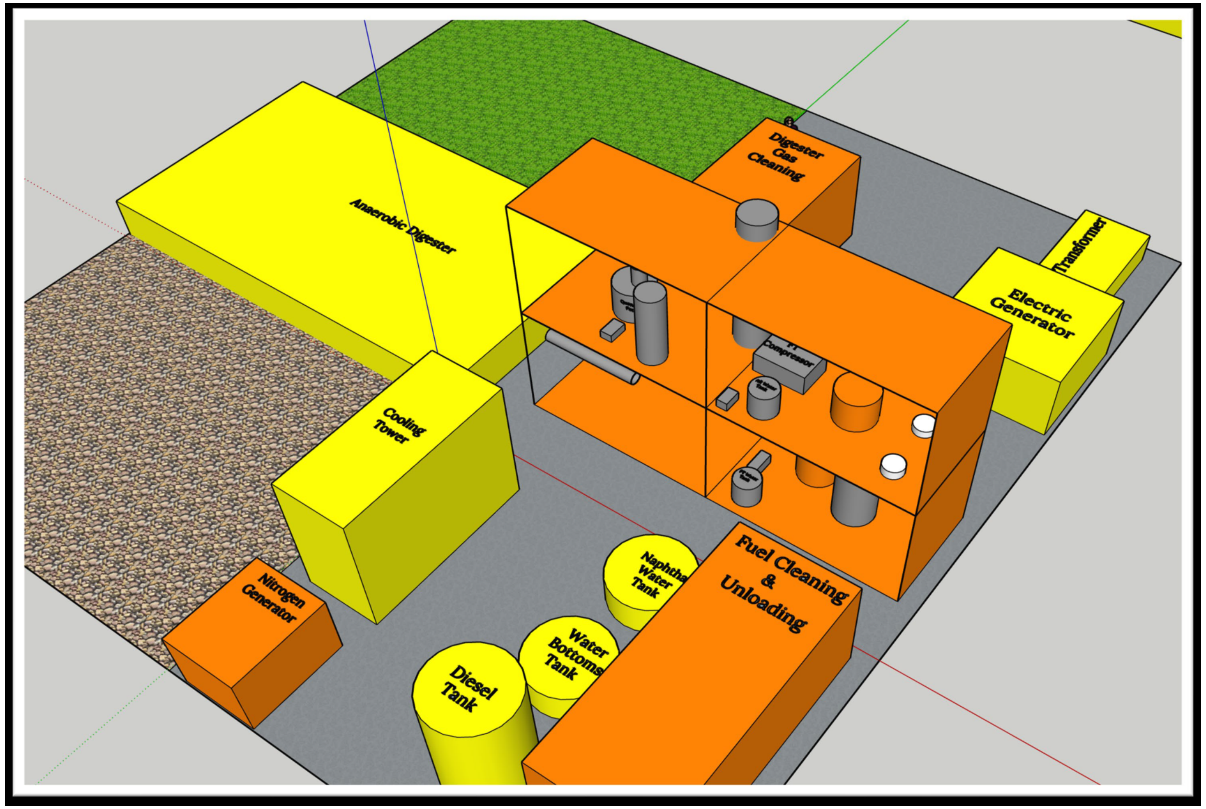
Progress and Outcomes

Phase I Remaining Needs

- NEPA and Environmental Assessment
- Biogas supply agreement finalized
- OSBL utility connections and power purchase agreement
- Construction and operation permit submission
- Financial close for phase 2
- Global documents and Issue for Design Validation Review

Phase II

- Detailed Engineering
- Construction
- Commissioning & Operation



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

Citrus County Chronicle: Landfill Partners for First in Florida Innovative Research

Pinellas County: Florida Wastewater to Clean Diesel

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 1.9 Billion D7 RIN Potential (Meet the liquid fuel gap!)
- Affordable Gas to Liquids Technology at Waste Industry Scale
- Dissemination of Results
  - Demonstrations Private & Municipal Level (Summary/Feasiblity Reports Distributed)
  - Five Patents Issued (5 more patents pending)
  - Peer Review Papers
  - Graduate & Undergraduate Research Engagement at USF

Impacts

Conversion efficiencies of TRIFTS vs. RNG processes.

Biogas Composition			LFG to RNG		TRIFTS	
Component	mol %	wt %	RNG Conv Effecency	Biofuel wt%	TRIFTS Conv Effecency	Biofuel wt%
Methane	56%	32.5%	90.0%	29.3%	90.0%	29.3%
Carbon Dioxide	42%	66.0%	0.0%	0.0%	40.0%	26.4%
			Overall Effecency	**29.3%**	**Overall Effecency**	**55.7%**

Financial comparison of TRIFTS vs RNG at 1,300 scfm biogas capacity

LFG to RNG		LFG to TRIFTS Diesel	
CAPEX	$14.0MM	**CAPEX**	$12.1MM
OPEX	$1.72MM/yr	**OPEX**	$1.56MM/yr
Annual Revenues		**Annual Revenues**	
RNG wholesale ($2.50/mmbtu)	$ 686,909	Diesel wholesale ($3.45/gal)	$ 3,136,826
D3 RINS ($31.04/mmbtu)	$ 8,528,377	D7 RINS ($5.20/gal)	$ 4,779,788
LCFS ($3.68/mmbtu @ CI=50 gCO2e/MJ)	$ 1,011,130	LCFS ($2.16/gal @ CI=-35 gCO2e/MJ)	$ 1,963,926
IRR Env. Attributes Included	65.1%	**IRR Env. Attributes Included**	59.9%
IRR Env. Attributes Excluded	**-69.8%**	**IRR Env. Attributes Excluded**	**8.00%**

Summary

- Production of drop-in renewable fuel and fertilizer
- Compatible with current waste industry scales
- Creation of circular economies at the rural and metropolitan levels
- Maximize the conversion of carbon within biogas (82% improvement in conversion efficiency vs current state of art)
- Profitable and competitive in the current market
- First of a kind demonstration facility producing over 1MM gal/year
  - 130% GHG reduction
  - MFSP < $2.50/GGE

Quad Chart Overview

Timeline
- *October 1st, 2021*
- *September 30th, 2026*

	FY22 Costed	Total Award
DOE Funding	*$29,097*	*$458,619*
Project Cost Share *	$297,513	$533,619

Project Goal
This project seeks to scale the technology to enable the construction and operation of a demonstration plant processing ~1,400 scfm of landfill gas to produce over 1,000,000 gal/yr of renewable diesel meeting a minimum fuel selling price of $2.50 while reducing GHG emissions by over 70% compared to petroleum derived fuels.

End of Project Milestone
Global documents and issue for design package submitted to DOE for phase I validation review.

Funding Mechanism
DE-FOA-0002396
FY21 BETO Scale-up and Conversion
Topic Area 1c: Demonstration Scale for Biofuels and Bioproducts

Project Partners
- US Gain
- Argonne National Lab

Let’s Connect

Sustainable Energy Solutions for The Waste Industry

Contact Info

Email: dwalker@t2cenergy.com

Ph: 813-334-7332

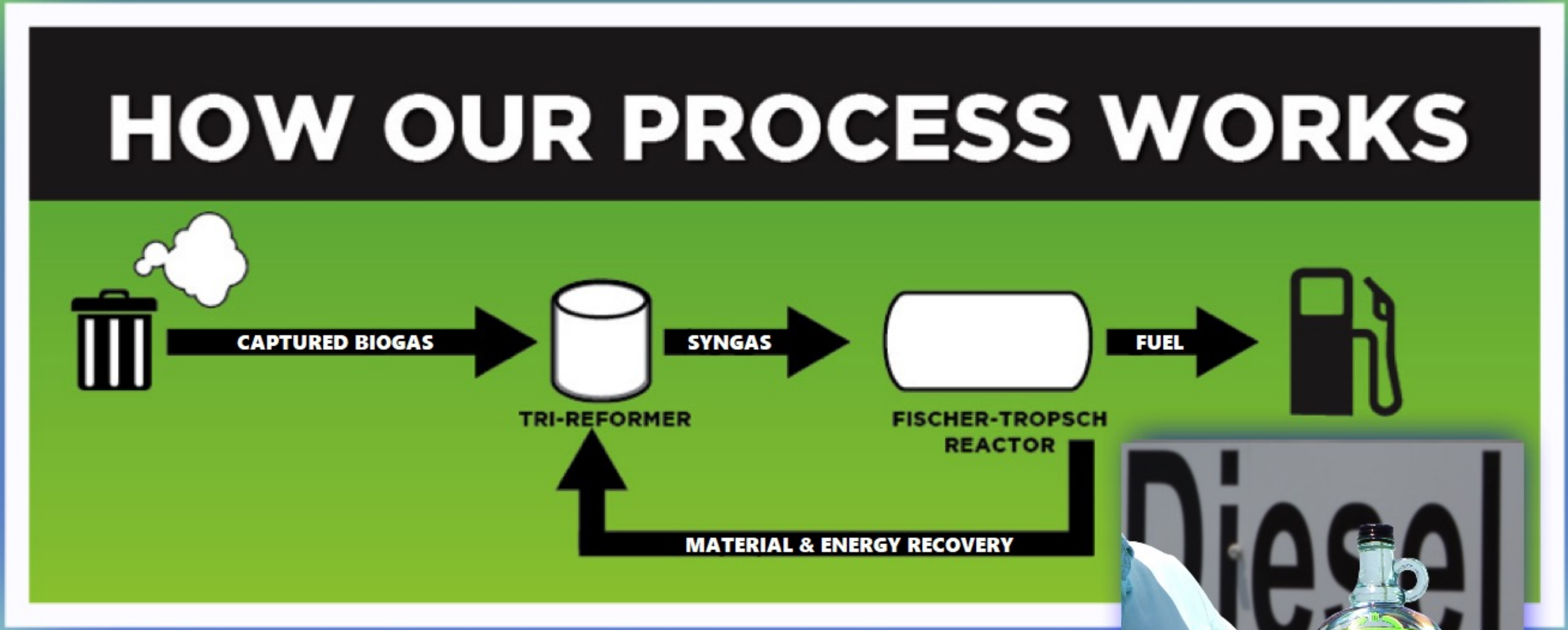
Fuel Testing

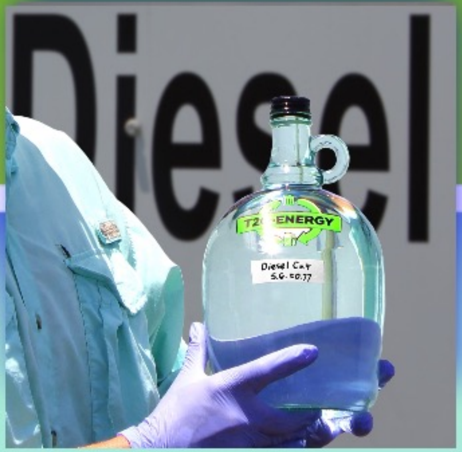
ASTM Method	EN Method	Lab Number	49673	TRIFTS DIESEL	Blend 27/73	Blend 27/73	ASTM D975		EN 590	
		Sample Code	Units	100% (neat)	Dairy/Com Diesel	Landfill/Com Diesel	min	max	min	max
D130 Fuels	EN ISO 2160	Copper		1A	1A	1A	-	No. 3	Class 1	Class 1
D2500	EN 23015	CloudPt	Deg C	-1	3	3	-	-	-	-
D2624	-	EConduct	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, Wastewater, Dairy Waste Derived Fuels
- Meet US and European Standards
- Cleaner Burning (Reduced SOx, NOx, and Particulates)
- Flexibility in Use and Distribution

Focus and Technology TRIFTS®

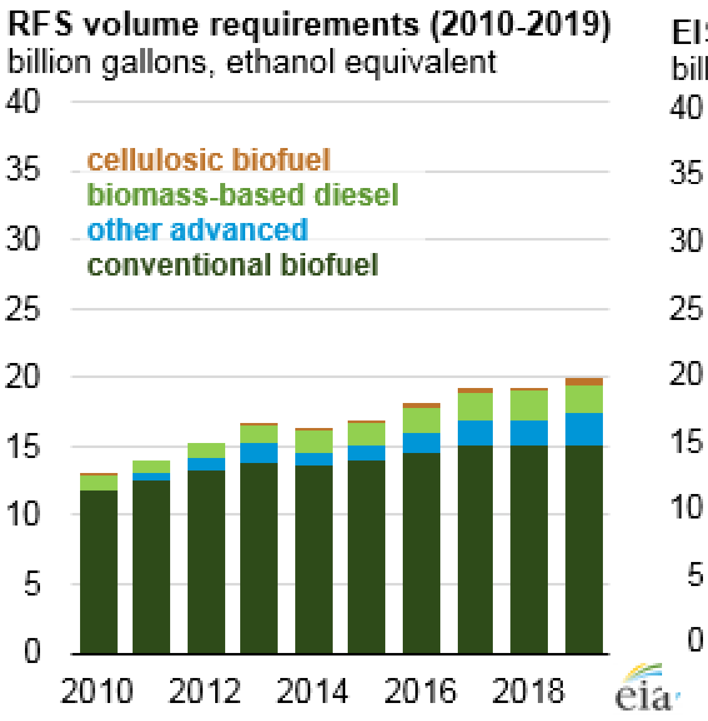
Profitable Gas to Liquids Technology at Waste Industry Scales

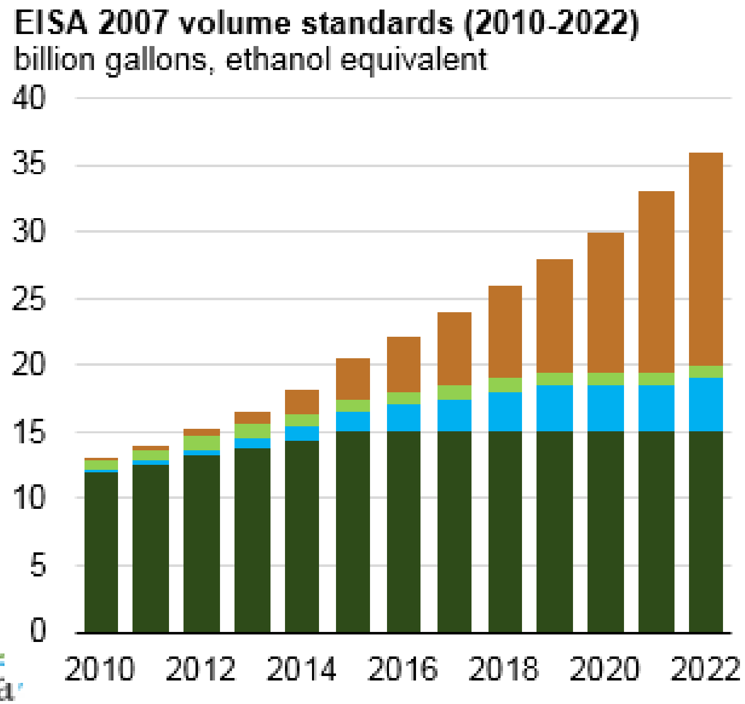




The U.S. Renewable Fuel Standard (RFS2)

- Enacted in 2005 / revised in 2007 as an energy security policy
- RINs are generated by renewable fuel producers
- Blenders generally purchase Renewable Fuel and blend it into diesel
    - Blender can now sell two commodities both physical fuel and separated RIN
- Obligated Parties must satisfy their Renewable Volume Obligations using/purchasing RINs





The U.S. Renewable Fuel Standard (RFS2)

- Each of the four Renewable Fuel Mandates has its own lifecycle GHG reduction criteria (established under EISA)
  - **Cellulosic Biofuel:** ***[Represented by D codes 3, 7]***
    - Must achieve 60% reduction vs. gasoline or diesel baseline
    - Cellulosic RIN production increasing due to new plants and biogas/CNG reclassification
  - **Biomass-Based Diesel:** ***[D codes 4, 7]***
    - Must achieve 50% reduction vs. diesel baseline
    - Includes Biodiesel and Renewable Diesel
  - **Advanced Biofuel:** ***[D code 5]***
    - Must achieve 50% reduction vs. gasoline or diesel baseline
    - Includes cellulosic, BBD, sugarcane ethanol and any other qualifying renewable fuel other than corn starch ethanol
  - **Total Renewable Fuel:** ***[D code 6]***
    - Must achieve 20% reduction vs. gasoline or diesel baseline; except:
      Existing (2007) facilities are "grandfathered", i.e., exempt to its 2007 baseline
    - Includes corn ethanol primarily
- Lifecycle emissions are evaluated by EPA as part of a "well to wheels" analysis, which supports various fuel pathways

The U.S. Renewable Fuel Standard (RFS2)

Renewable Fuels produced from these feedstocks using an approved technology can generate "Cellulosic Biofuel" D3 or D7 RINs

- Agricultural Residues
- Switchgrass
- Miscanthus
- Separated Yard Waste
- Separated Food Waste
- Biogenic separated MSW
- Annual Covercrops
- Forest Product Residues
- Forest Thinnings
- Slash
- Arundo Donax
- Pennisetum purpureum
- Biogas from municipal wastewater treatment facility digesters
- Biogas from agricultural digesters
- Biogas from separated MSW digesters
- Biogas from the cellulosic components of biomass processed in other waste digesters
- Arundo Donax
- Energy Cane
- Bagasse
- Bagasse Straw

Cellulosic feedstocks are evaluated based on their cellulosic content

TRIFTS Renewable Diesel Value Components

- **LCFS credits stack on top of RIN, Physical fuel value, and Blenders tax credit**
- **Renewable Diesel – August 2022 ($/gal)**
  - Physical fuel + CAR = $3.45
  - D3 RIN = $5.20 (1.7 EV x 3.06)
  - LCFS = $2.16 (TRIFTS has <u>**-36**</u> gCO2e/MJ CI score)
  - <u>Blenders Credit = $1.00</u>
  - **Total = $11.81 / gal**

CAR = Cap-At-The-Rack is a premium paid for conventional diesel under the California Cap and Trade program, LCFS and RIN value is NOT passed through to rack under this arrangment

Carbon Intensity Based Standards

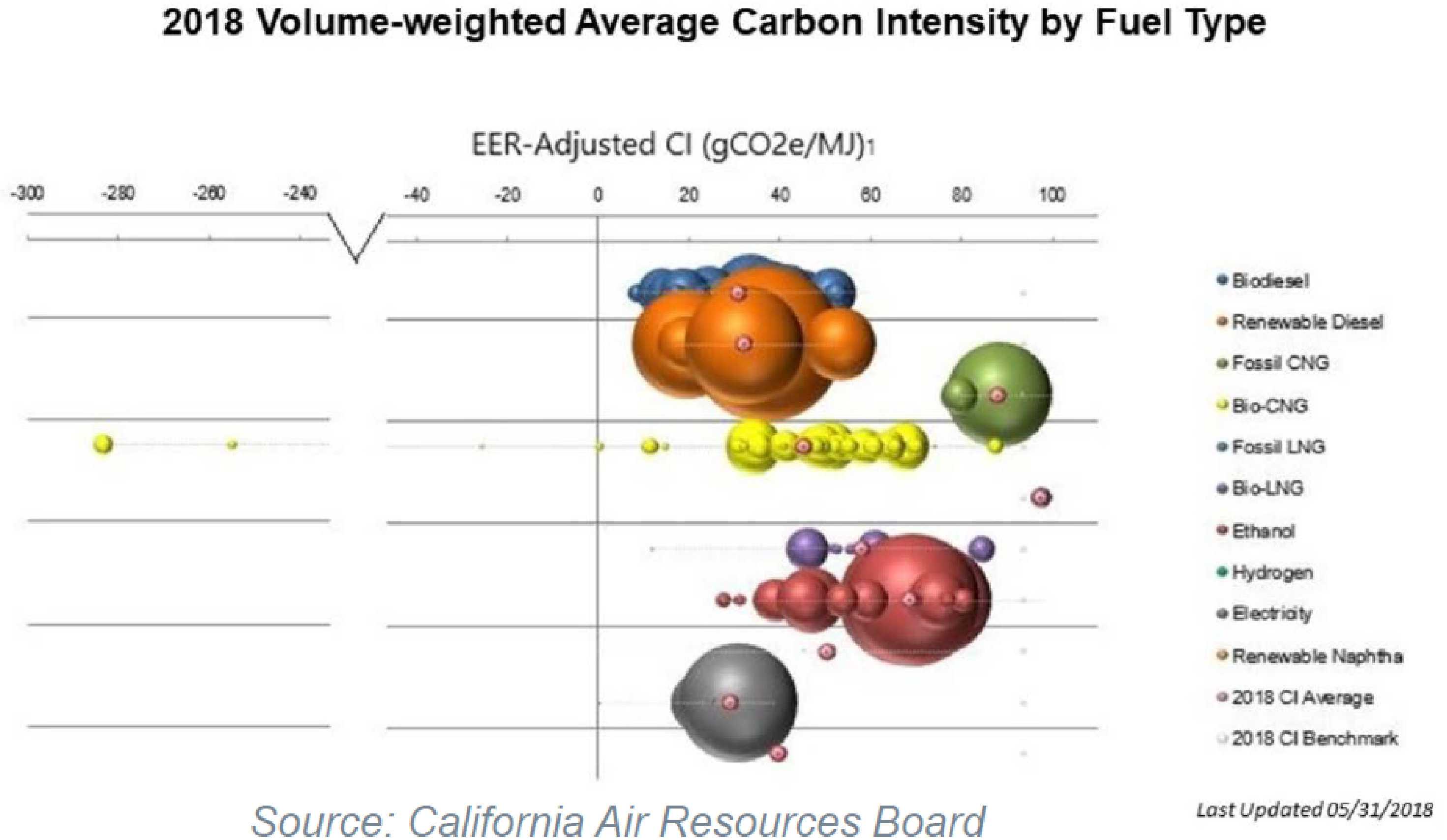
Diesel Carbon Intensity (CI) standard = 94.17 $gCO2_e$/MJ (2019)

- *Diesel has an energy density of 134.47 MJ/gal*

Credits generated are proportional to the difference between the low carbon fuel and the standard

- *i.e. against a standard of 94, an LFG facility with CI of 54 gCO_2/MJ generates half the credits of a facility with a CI of 14 gCO_2/MJ*

Facilities can have a negative CI when including avoided non-CO_2 GHG emissions (i.e. methane)



Source: California Air Resources Board