DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

R-GAS™ Advanced Gasification Pre-Pilot Demonstration for Biofuels (BioRGAS)

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Systems Development and Integration Session B

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Project Overview

- The ***R-GAS™ Advanced Gasification Pre-Pilot Demonstration for Biofuels (BioR-GAS)*** *project has been awarded to GTI under DE-FOA-0002396 in September 2021 and officially kicked-off in January 2022.*

- *The project goal is to demonstrate that drop-in aviation, diesel, and marine fuels can be produced at commercial scale from biomass and SMSW for less than $2.75 per Gallon of Gasoline Equivalent (GGE) (with a stretch goal of less than $2.50/GGE), and with a reduction in greenhouse gas (GHG) emissions of greater than 70% over the petroleum derived equivalent (with a stretch goal of greater than 80%).*

- *The current research effort will ultimately inform whether entrained flow gasification can be technically and economically viable for woody biomass and SMSW feedstocks to produce biofuels via the Fischer-Tropsch (FT) pathways.*

Approach

- *The technical approach to achieve the project goals is divided into two main parts. The first part takes place in BP2 and consists of the following:*
  - *Corn stover (CS) and sorted solid municipal solid waste (SMSW) preparation and characterization through torrefaction, steam-explosion (SE) and non-thermal drying (NTD).*
  - *Flowability testing through the R-GAS pilot facility ultra dense phase (UDP) feed system*
  - *Techno-economic analysis (TEA) of feedstock preparation through torrefaction, steam-explosion, and NTD,*
- *The second part takes place in BP3 and consists of the following:*
  - *R-GAS entrained flow gasification testing in the R-GAS pilot facility at greater than 6-standard ton per day (STPD) scale*
  - *TEA and lifecycle analysis (LCA) to confirm the cost and GHG emission reduction targets for biofuels production through FT pathways can be achieved at commercial scale.*
- *The main potential challenges/risks facing the technical approach are the following:*
  - *Irregular particle morphologies of pulverized CS and SMSW → risk of feedstock bridging in the feed hopper system as well as plugging the feedstock supply line to the gasifier.*
  - *Inability to achieve small enough particle size distribution that are small enough → risk of inadequate carbon conversion during the gasification process.*

Approach (cont'd)

- *Two Go - No Go (GNG) decision points are scheduled as entry criteria into BP2 and BP3. GNG1 decision has been already made to proceed from BP1 to BP2 as GTI has shown an acceptable baseline for the project and an acceptable path to meeting project metrics. In Q2 of 2023, after the feed system testing, the GNG2 decision to proceed from BP2 to BP3 will be made based on GTI demonstrating that* ***at least one feedstock/pre-processing approach*** *can be reliably pressurized and transported into the gasifier at a particle size distribution and pressure, and a* ***capital and operating cost consistent with meeting the $2.75/GGE target****.*
- *The main goal in BP3 is to have* ***100 hours continuous and 500 hours cumulative time on stream*** *as well as final gasification tests to ensure feedstock flowability.*
- *The current project has received several* ***lessons learned from another similar project led by GTI*** *and involving torrefied wood chips feeding.*
- *GTI's approach to addressing diversity, equity, and inclusion in this project includes the following:*
  - *Training/mentorship for PIs and Key Personnel on* ***GTI's D&I educational program***
  - *Training for PIs and Key Personnel on* ***Unconscious Bias and Microaggression***
  - *Conducting an* ***outreach program to minority-based high school in the Chicago area*** *whereby the high-school students will be introduced to the emerging sustainable aviation fuels (SAF) industry and the future job opportunities that it will offer*

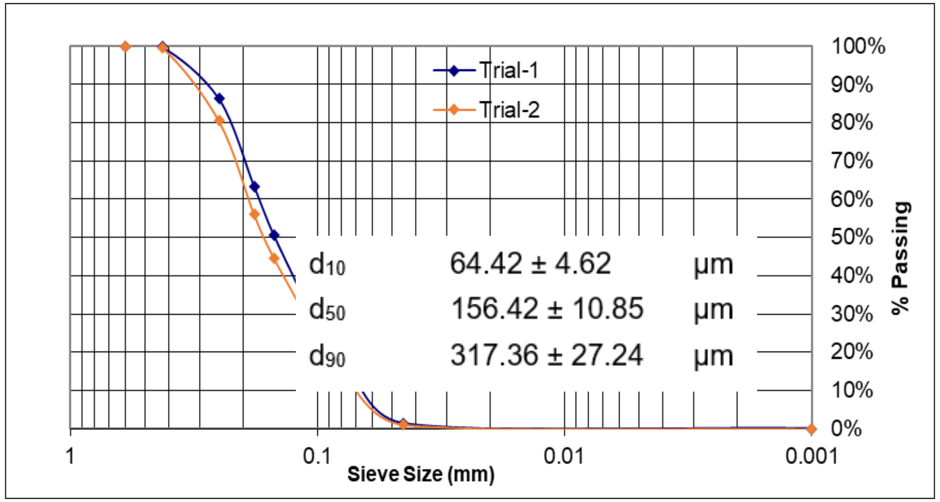
Progress and Outcomes: Project management summary

- The progress on the project deliverables is shown in the table below

Number of Task, Subtask, Milestone, Deliverable including Go No/Go Decision Points	Title - Tasks, Subtasks, Milestones, Deliverables including Go No/Go Decision Pts	Performer(s)	Start Date *(Tasks, Subtasks Only)*	Original Planned Completion Date *(Tasks and milestones)*	Approved Updated Completion Date	% Completion Planned	% Actual Completion	Actual Milestone/deliverable/decision Completion Date	Task or Milestone Completion Criteria method of measurement (may include cost and performance metrics)
1	Initial Verification	GTI, INL, Ekamor	3-Jan-22	31-Mar-22		100%	100%	31-Mar-22	
GN.1	Initial verification Go/No-Go	GTI, INL,	3-Jan-22	31-Mar-22		100%	100%	31-Mar-22	Initial Verification Report
2	Program Management	GTI	1-Apr-22	30-Jun-24		40%	40%		
3	Selection of Feedstocks and Pre-	GTI,INL,	1-Apr-22	31-Mar-23		80%	70%		
D 3.2	- Technoeconomic Analysis of Pre Processing Approaches Report	GTI	1-Apr-22	21-Jun-22		100%	100%	30-Jun-22	List of specific biomass and SMSW source, drying and pulverizing processes and target PSD’s
M 3.3.1	Flow test feedstock preparation	INL, Ekamor	1-Jun-22	16-Sep-22		100%	80%		Delivery receipt for test
M 3.3.2	Feedstock Characterization	GTI, INL,	1-Aug-22	16-Oct-22		100%	75%		Analysis Summary
M 3.3.3	Flow Test Planning Complete	GTI	1-Sep-22	16-Oct-22		100%	100%	31-Dec-22	Test Plan
M 3.3.4	Facility Preparation Complete	GTI	1-Sep-22	15-Nov-22		100%	100%	31-Dec-22	Flow test Facility Readiness
M 3.3.5	Flow Testing Complete	GTI	1-Nov-22	20-Mar-23		50%	0%		Test log summary
M 3.3.6	Flow Test Data Analysis and	GTI	1-Jan-23	14-Apr-23		25%	0%		Analysis Summary and
D 3.3	Flow Tests of Selected	GTI	1-Jun-22	21-Apr-23		5%	0%		Analysis Summary and
GN-2	Intermediate and Final Verification	GTI	1-Apr-22	21-Apr-23		5%	0%		Approval of selections for
4	Injector Design and Fabrication	GTI	1-Nov-22	30-Jun-23		25%	25%		
M 4.1	Injector Design Complete	GTI	1-Nov-22	31-Mar-23		50%	50%		Injector Design complete

Progress and Outcomes: Torrefaction feedstock prep

- CS pellet torrefaction has been conducted at ~245 degC temperature and a residence time of 30 minutes.
- CS feedstock torrefaction preparation process has met the 1000-micron max particle size.
- Achieving particle size distributions under 200-micron was not possible due exponential increase in energy requirement and severe throughput reduction.
- The pulverized torrefied CS was recycled twice; the equilibria recycle ratio is ~1.28 and the mass loss was ~1.5%.



Deconstruction (<6.5 mm)

20.4 kWh/ton-out

Pelletization

98 kWh/ton-out

Torrefaction

Exothermic

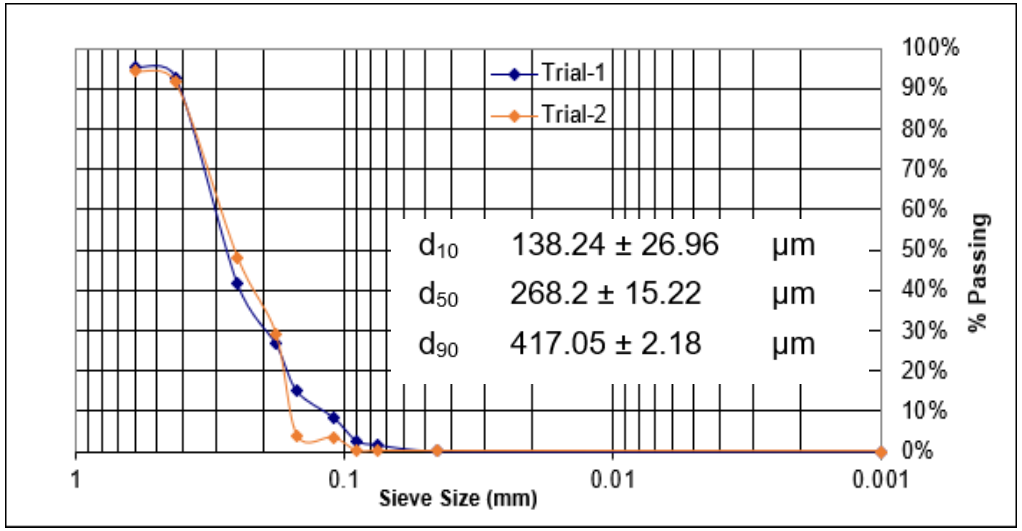
Grinder

9.5 kWh/ton-out

Torrefaction overall process energy requirement: ~128 kWh/ton-out

Progress and Outcomes: Steam-explosion feedstock prep

- CS SE has been conducted at 150 psi pressure and a residence time of 20 minutes.
- CS SE preparation process has met the 1000-micron max particle size.
- Achieving particle size distributions under 200-micron was not possible due exponential increase in energy requirement and severe throughput reduction.
- The pulverized SE CS was recycled twice; the equilibria recycle ratio is ~1.59 and the mass loss was ~2%.



SE overall process energy requirement: ~553 kWh/ton-out

Progress and Outcomes: NTD CS feedstock prep

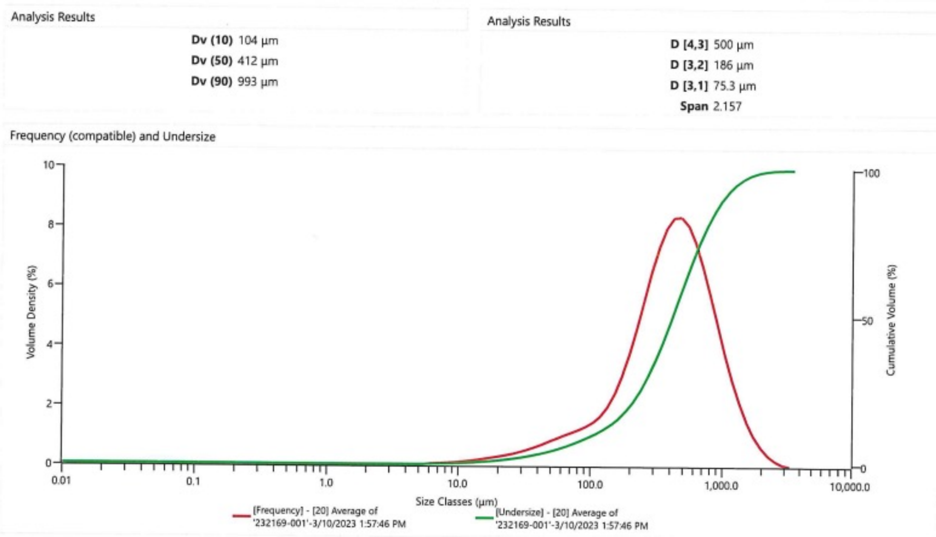
- Material is fed in from top of mill where it hits 3 sets of hammers on a rotating shaft (pictured). There is a set of grates/screens that can be placed at any combination that effects residence time in the mill and size pulverization.
- NTD is a hypothesized process in which the hammer mechanically forces moisture out of the feedstock creating a vapor saturated environment. The hammering action also leads to fine dust particles (<7 micron) which become nucleation sites for the vapor. The hammer motion induces airflow that carries the moist dust particles out of the system.

Hammer Mill first run pelletized corn stover

Rotating shaft & hammers

Progress and Outcomes: NTD CS feedstock prep (Cont'd)

- CS feedstock NTD preparation process has met the 1000-micron max particle size condition.
- Achieving particle size distributions under 200-micron was not possible due exponential increase in energy requirement and severe throughput reduction.
- The pulverized NTD CS was not recycled during the tests ran by Ekamor, and the mass loss was ~11.3%. This mass loss can be minimized with recycling.



Hammer-mill

90 kWh/ton

Moisture < 12%

Pelletizer

61 kWh/ton

Grinder

20 kWh/ton

NTD overall process energy requirement: ~171 kWh/ton-out

Progress and Outcomes: Comparison among torrefaction, steam explosion, and NTD

- The CS torrefaction approach has shown the lowest energy requirements in kWh per ton of pre-processed CS feedstock as well as per energy input to the gasifier.

Corn Stover Pre-processing Method (with 26% initial moisture)	Energy Requirments per ton output (kWh/ton)	Total input mass lost in process (%)	Feedstock energy density to the gasifier (kJ/kg)	Energy requirements per kJ of energy input to the gasifier (kWh/kJ)
Torrefaction	127.9	17.1%	18,840	**6.1**
Steam Explosion	553	2.0%	17,990	**27.8**
Non-thermal Drying	171	2.0%	17,650	**8.8**

For all three methods, the CS bales have been sourced from the same origin in Iowa

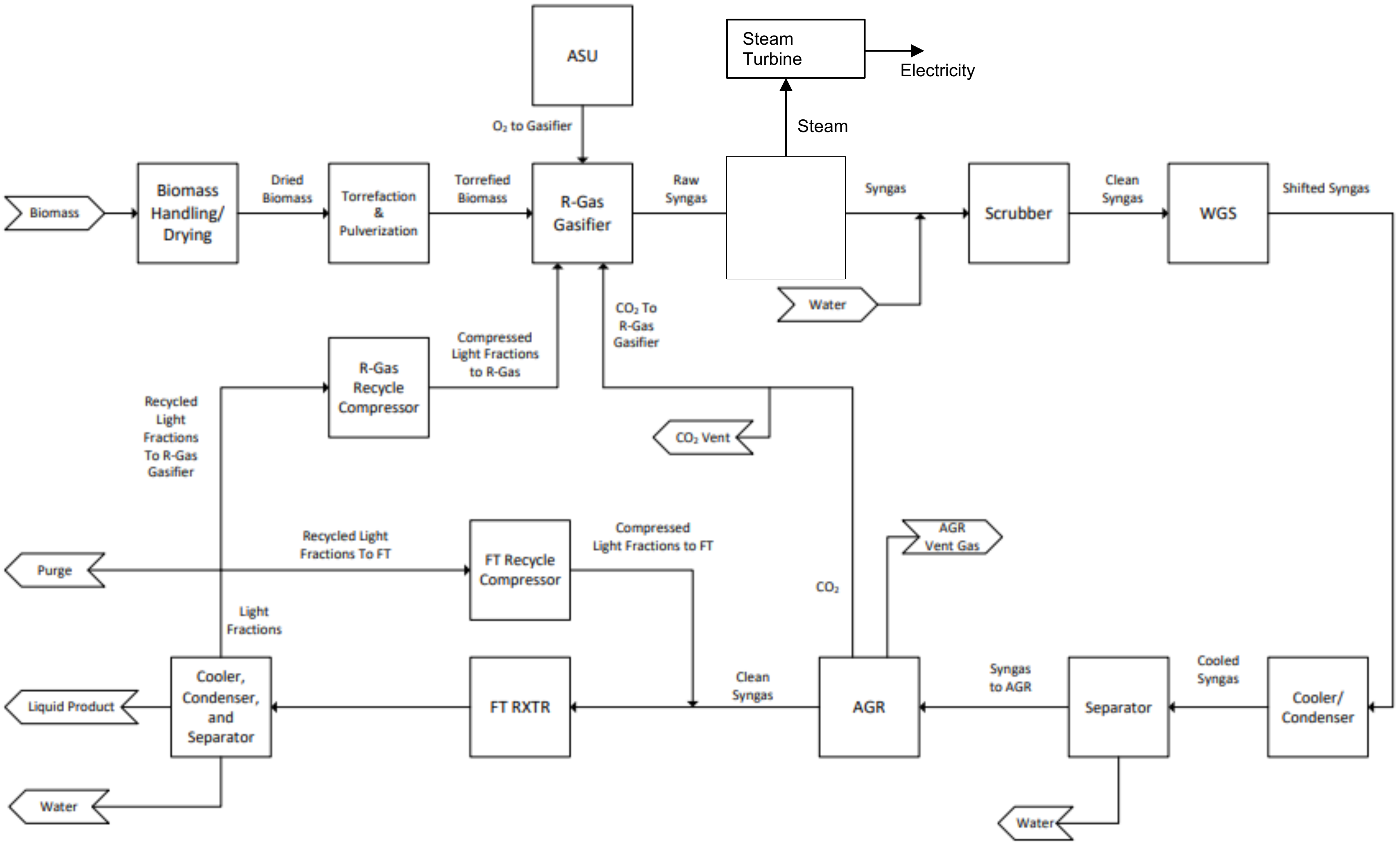
Progress and Outcomes: CS feedstock prep TEA

- NTD is by far the most economical pre-processing method, however it is still need to be demonstrated in terms of being fed into the gasifier and being converted to syngas.
- OPEX of SE and as such this method will not be selected for gasification testing.
- The Yilkins torrefaction technology is applied for the R-GAS biorefinery TEA study in BP2.
- An important trade is planned for BP3 between the torrefaction pathway and the NTD pathway to determine which ultimately will result in a lower $/gal of biofuels.

Technology	Torrefaction - Yilkins	Steam Explosion	Non-thermal Drying - Ekamor
Installed Capacity (TPD)	548.00	75.00	104.55
Total Installed Cost	$ 45,950,000.00	$ 19,880,600.00	$ 4,518,150.00
TIC per Ton installed	$ 83,850.36	$ 265,074.67	$ 43,215.21
Capital Charge factor	8.00%	8.00%	8.00%
Capacity Factor	100%	100%	100%
CAPEX per Ton	$ 18.38	$ 58.10	$ 9.47
Moisture Content	50%	50%	50%
Total Opex Cost	$ 10,705,262.20	$ 4,036,440.00	$ 1,576,404.90
OPEX per ton produced	$ 53.52	$ 147.45	$ 41.31
Pre-processed Biomass Cost $/ton produced (W/o Feed)	**$ 71.90**	**$ 205.55**	**$ 50.78**

Progress and Outcomes: R-GAS biorefinery block flow diagram (BFD)

- The gasifier is operated at a temperature of >1300 degC to ensure melting all the slag.
- Heat is recovered from the syngas stream after a partial quench.
- The FT unconverted gases are recycled back to the R-GAS gasifier where they are co-injected with the solid feed.
- Carbon Utilization is ~37%



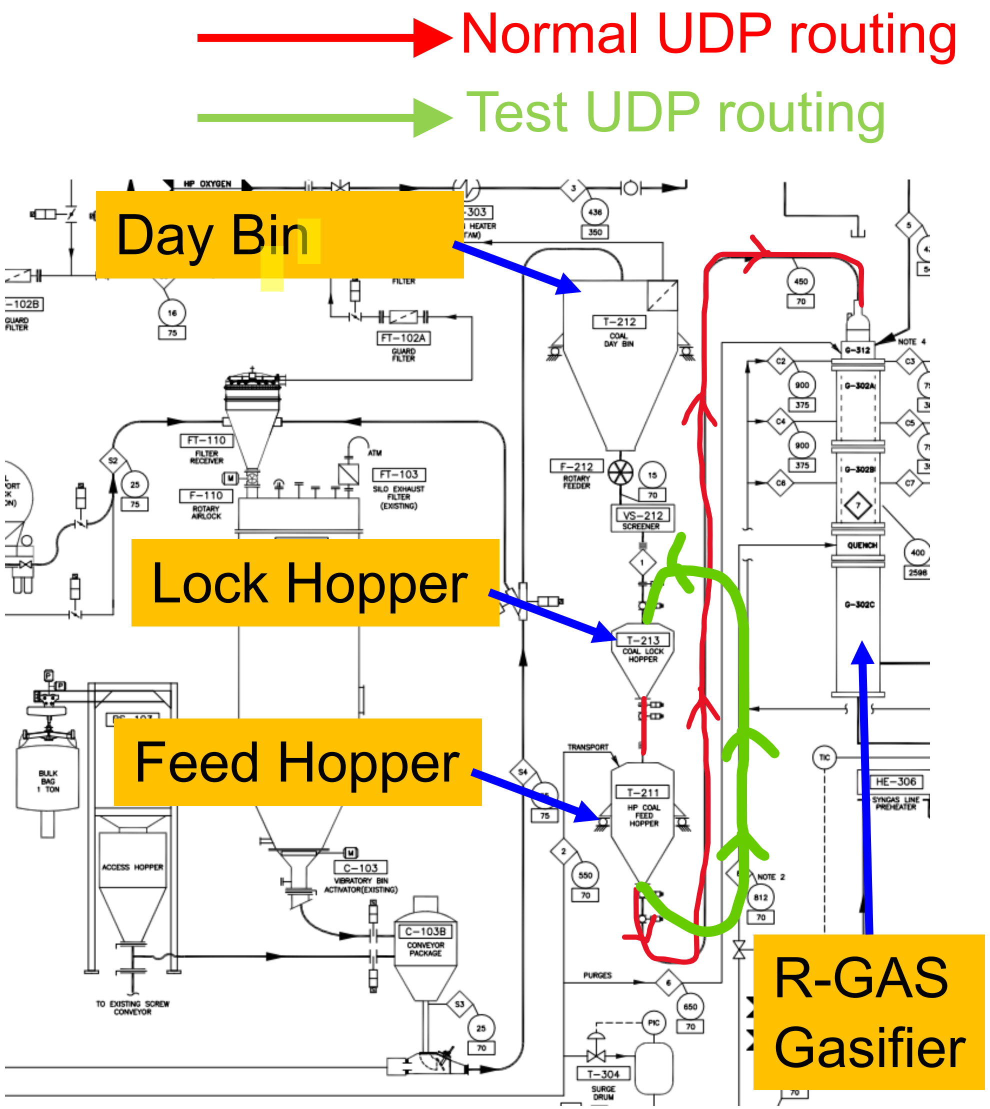
Progress and Outcomes: R-GAS biorefinery TEA

- The input to the current R-GAS biorefinery TEA is based on the '*Ex Situ Catalytic Fast Pyrolysis of Lignocellulosic Biomass to Hydrocarbon Fuels: 2018 State of Technology and Future Research*' NREL report with 2022 projection.
- The R-GAS Biorefinery economics benefit greatly from (1) the gasification island low CAPEX and (2) the sales of net power output resulting from significant heat recovery from the syngas.
- 15% project contingency was used.

R-GAS Biorefinery		
Installed Capacity (BPD)		1340
Biomass Handling CAPEX	$	38,370,572
ASU CAPEX	$	24,180,090
Gasification Island CAPEX	$	54,671,015
WGS and AGR CAPEX	$	38,449,673
FT Island and Power Island CAPEX		$209,543,619
Total Installed Cost	$	365,214,969
TIC per BBL installed	$	272,450
Capital Charge factor		8.00%
Capacity Factor		90%
CAPEX per BBL	**$**	**66.35**
Cost of biomass delivered per ton	$	70.00
Biomass moisture content		15%
Biomass consumption dry ton per day	$	865.12
Net Power Produced (MWe)	$	17.29
Price of electricity sold to grid per kWh	$	0.06
Total Opex Cost	$	26,322,602
OPEX per BBL produced	**$**	**59.78**
$/BBL produced	$	126.13
$/gallon produced	**$**	**3.00**
$/tonne biofuels produced	$	986

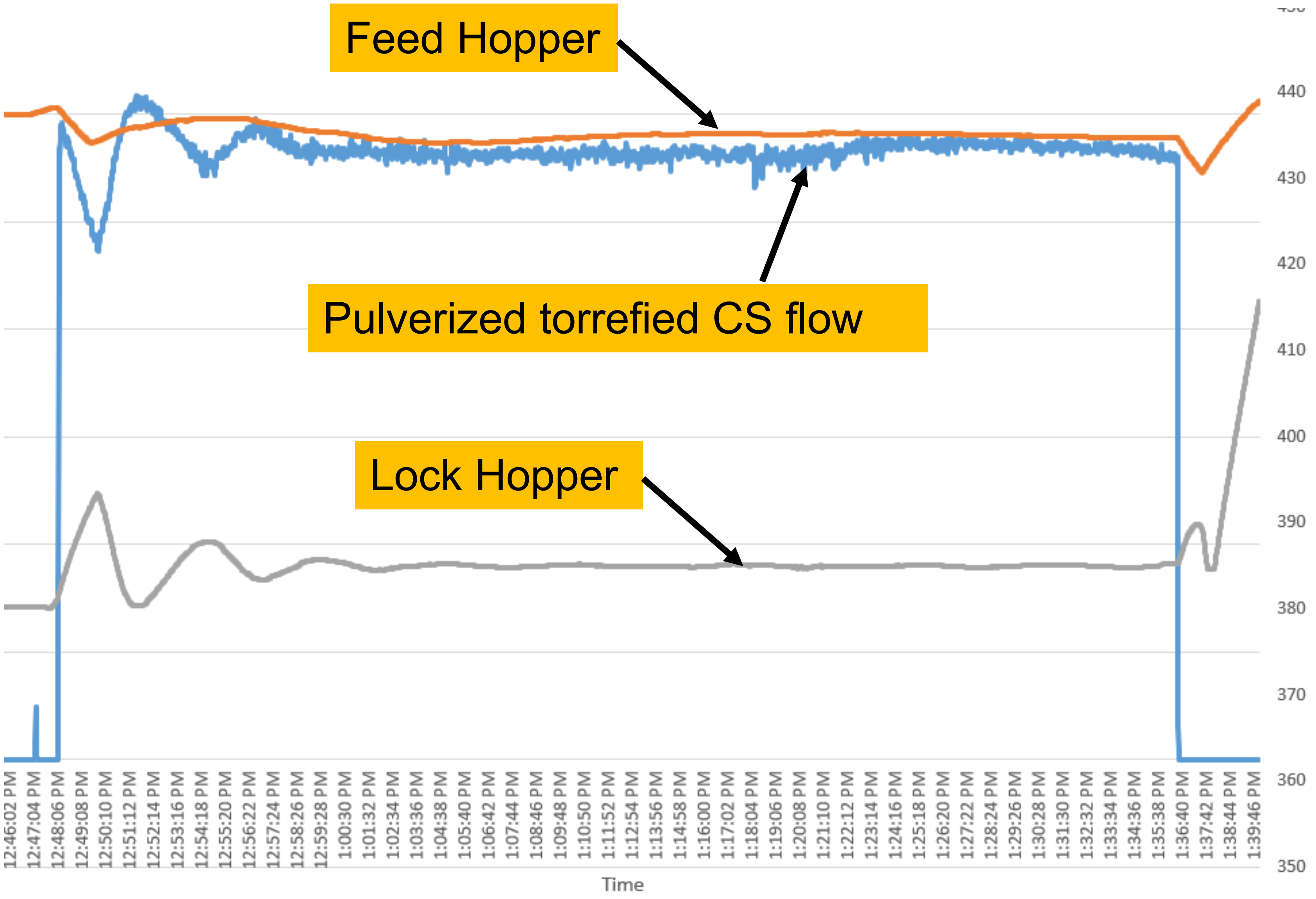
Progress and Outcomes: UDP flowability testing – pulverized torrefied CS

- During normal gasifier operation, the pulverized feedstock is received in the day bin and then it is transferred to the lock hopper where it is pressurization/de-pressurization cycles.
- Upon being pressurized in the lock hopper, the pulverized feedstock is transferred to the feed hopper where it get isolated and started feeding the R-GAS gasifier through a < 1 in. diameter UDP line.
- During the UDP flowability testing, the lock hopper is used to simulate the pressure conditions in the gasifier.



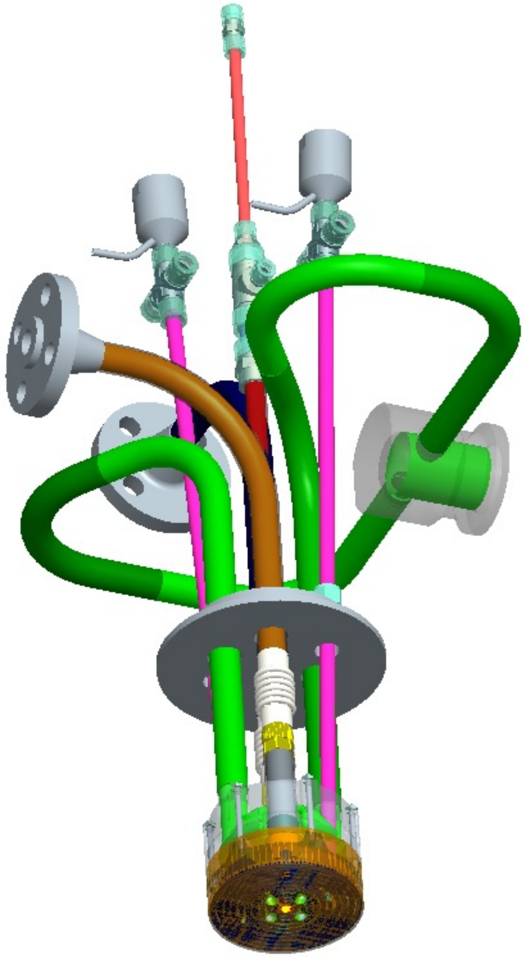
Progress and Outcomes: UDP flowability testing – pulverized torrefied CS (Cont'd)

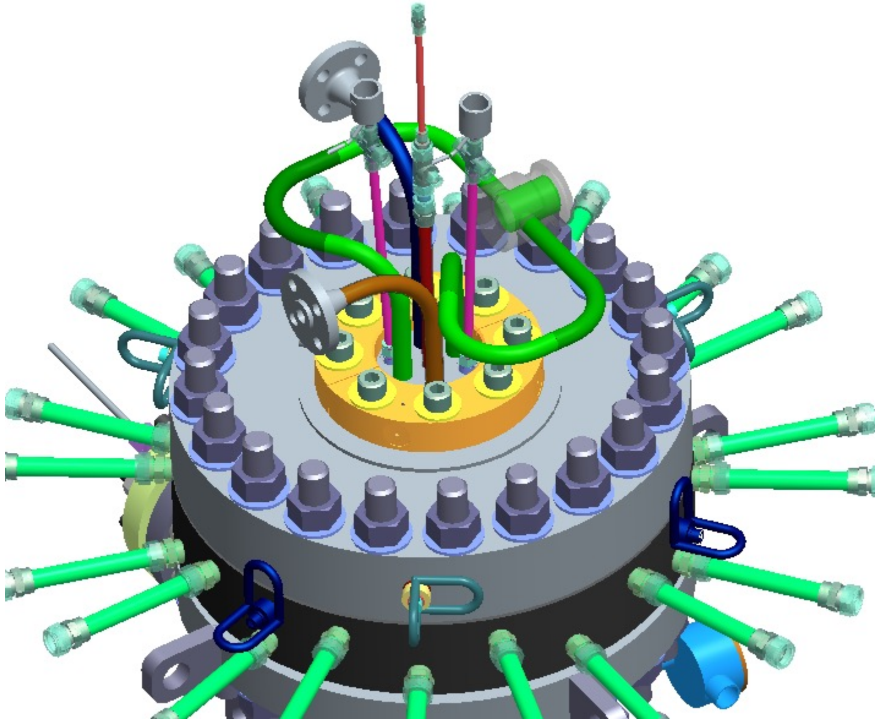
- The project team was able to achieve one successful UDP flowability test for 48 minutes transferring ~940 lbs. of CS from the feed hopper to the lock hopper.
- Unfortunately, the run was not repeatable due to plugging issues in the UDP line.
- System modifications are underway to mitigate the plugging issues.



Progress and Outcomes: Injector Design

- Novel R-GAS pilot dual-fuel injector designed to enable co-injection of the FT unconverted gases with the pulverized CS/SMSW feedstocks.





Impact

- *If successful, this project will have impact on the transportation industry (aviation, marine, rail, long-haul trucking, etc.) and beyond by establishing a viable pathway to produce low-cost low-carbon syngas.*
- *Other industries that rely on syngas as a building block for their final products will also benefit form the success of this project. Those industries include but are not limited to the chemical industry (methanol, liquified petroleum gas or LPG, ammonia, etc.), the steel industry for direct reduced iron (DRI) applications, and the power generation industry for integrated gasification combined cycle (IGCC) or Allam cycle applications.*
- *Implementing entrained flow gasification with biogenic feedstocks will result in reduced CAPEX and OPEX due to elimination of tar reformation and down-sizing of air separation capacity.*
- *Research results are planned to be presented at the following two conferences in 2023:*
  - *11th International Freiberg Conference on Circular Carbon Technologies*
  - *2023 Global Syngas Technologies Conference*

11th International Freiberg Conference
on Circular Carbon Technologies
Towards a Net-Zero
Carbon Economy
24–29 September 2023
Rotterdam, Netherlands

GSTC
GLOBAL SYNGAS
TECHNOLOGIES COUNCIL

- *Discussions are ongoing with two major global industrial players in SAF and Methanol*

Summary

- *The **R-GAS™ Advanced Gasification Pre-Pilot Demonstration for Biofuels (BioR-GAS)** project key objectives were elaborated*
- *Project challenges/risks and associated mitigations have been discussed*
- *Technical approach for three different methods for feedstock preparation (**torrefaction, steam-explosion, and NTD**) have been explained along with relevant techno-economic evaluations.*
- ***Feedstock flowability results** in the R-GAS pilot UDP feed system have been presented and discussed based on three feedstock preparation methods → Feedstocks prepared by methods A and B have been down selected to be used for the gasification testing in BP3.*
- ***Major industries** that are impacted by this project have been highlighted.*
- *2023 **conferences** where the current research results will be disseminated have been announced.*

Quad Chart Overview

Timeline
- *19-January-2022*
- *30-June-2024*

	FY22 Costed	Total Award
DOE Funding	*$972,208*	*$4M*
Project Cost Share *	*$208,949*	*$1M*

TRL at Project Start: TRL 4
TRL at Project End: TRL 6

Project Goal
The project goal is to demonstrate that drop-in aviation, diesel, and marine fuels can be produced at commercial scale from biomass and SMSW for less than $2.75 per Gallon of Gasoline Equivalent (GGE) (with a stretch goal of less than $2.50/GGE), and with a reduction in greenhouse gas (GHG) emissions of greater than 70% over the petroleum derived equivalent (with a stretch goal of greater than 80%).

End of Project Milestone
- *Fuel selling price <$2.75/GGE, stretch goal <$2.50/GGE*
- *GHG reduction >70%, stretch goal >80%*
- *500 hours cumulative testing complete*

Funding Mechanism
DE-FOA-0002396 - Topic Area and subtopic: 1a .

Project Partners*
- Idaho National Lab
- Ekamor Resource Corporation

*Only fill out if applicable.