DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Cool GTL for the Production of Jet Fuel from Biogas Award EE-0008507

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Systems Development and Integration B

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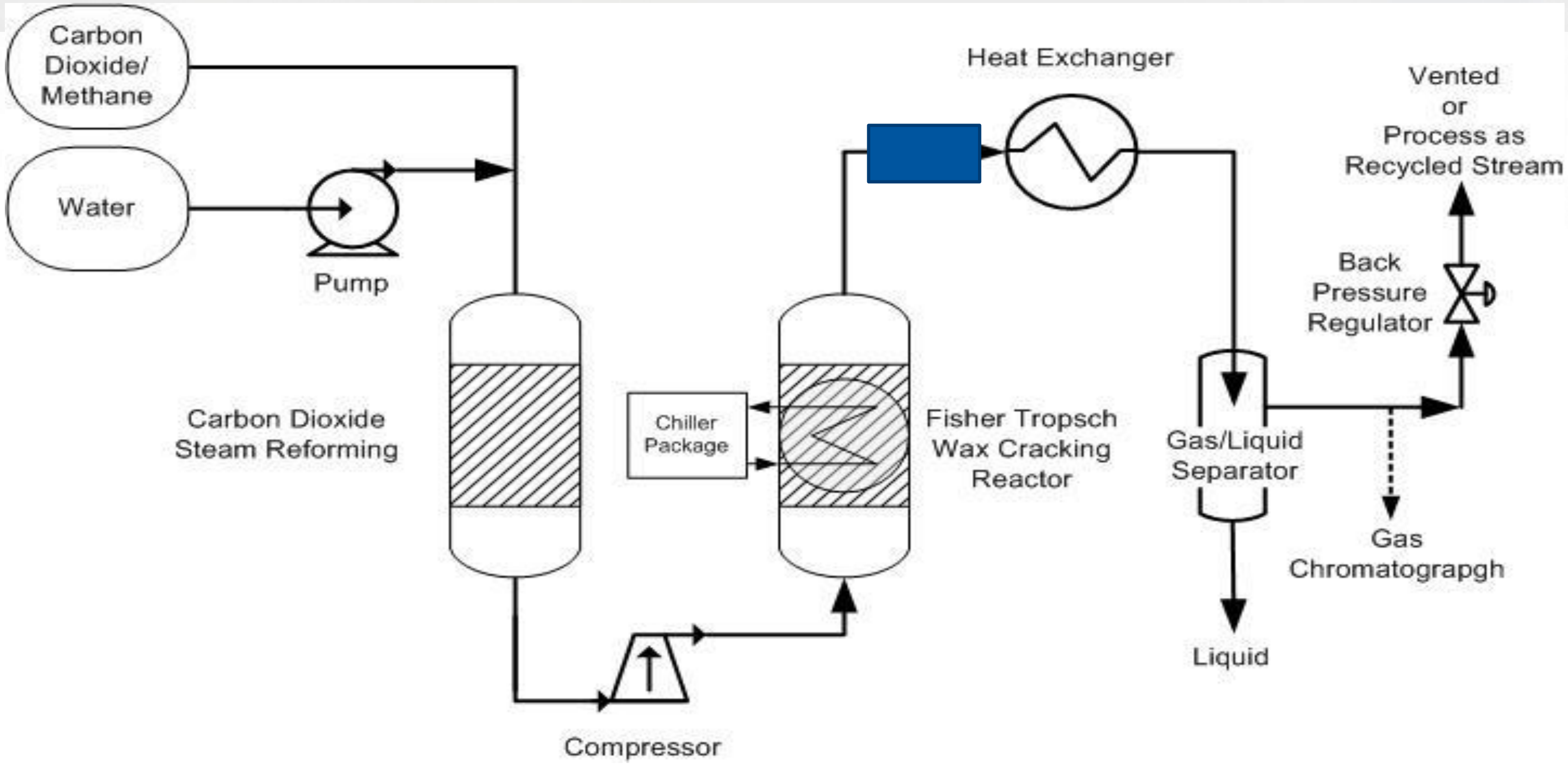
GTI ENERGY
solutions that transform

PROJECT OVERVIEW

Cool GTL



- Converts CO_2-rich methane, ethane and propane to high-quality gasoline, diesel and jet fuel
- Works well for any gas containing CO_2 or CO
- Uses unique CO_2/steam reforming catalyst to directly make 2:1 H_2/CO synthesis gas
- Uses unique combined Fischer-Tropsch and wax-cracking reactor
- Simple and compact with unique catalysts in each stage

What's Unique and Different about Cool GTL?

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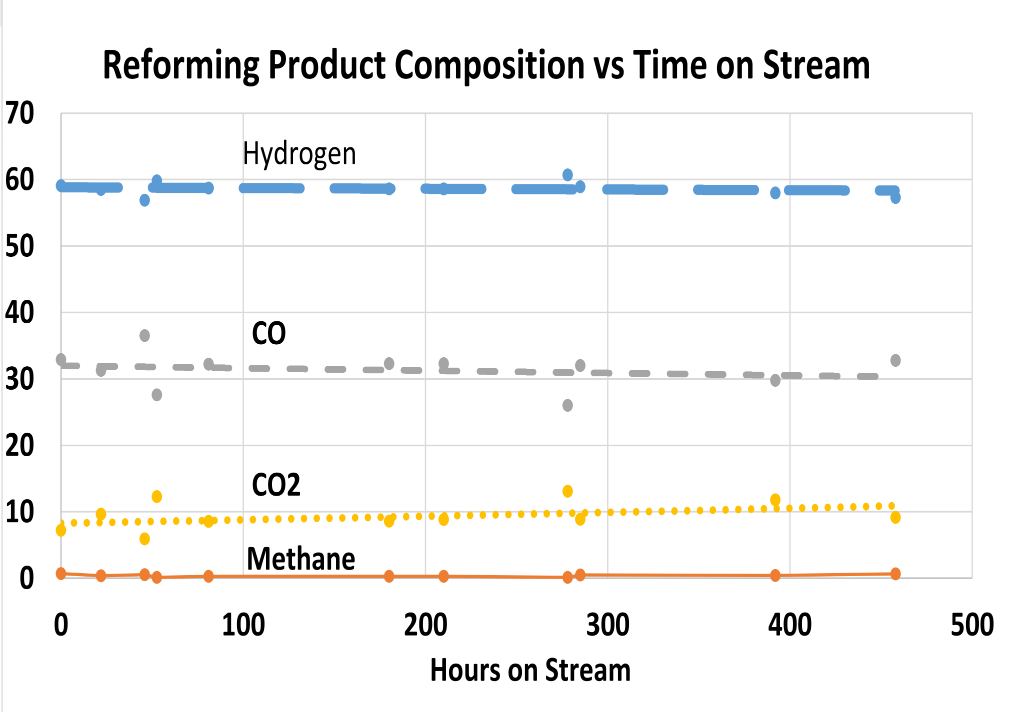
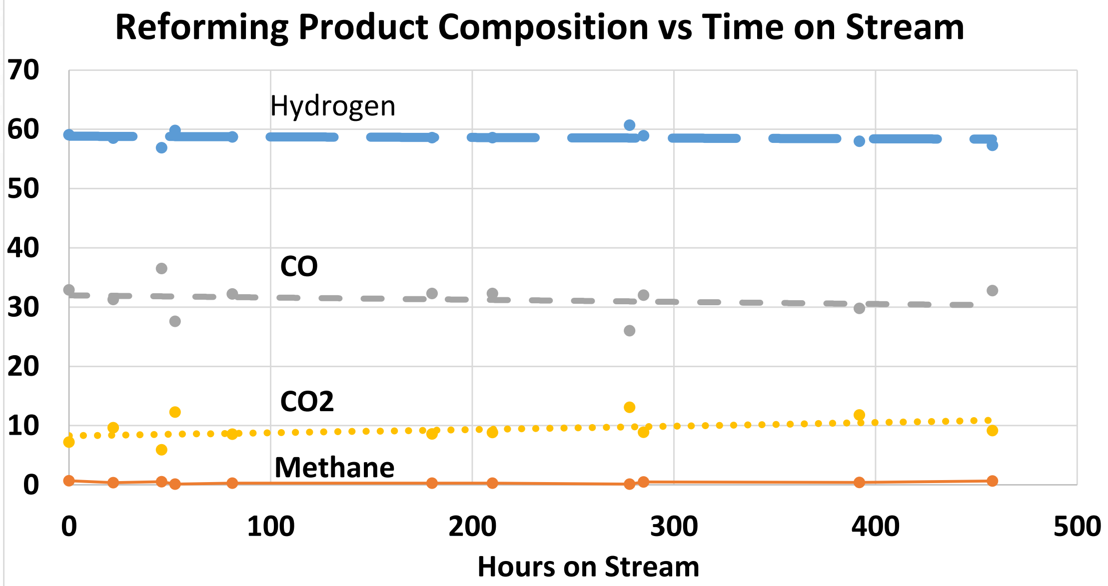
- **Unique Catalyst in Cool Reforming Step**
  - Robust with long life - minimal coking
  - Directly makes 2/1 H_2/CO synthesis gas by adjusting amount of steam added
  - Simple and direct, mild temperatures, steady performance
- **Unique Catalyst in Fischer-Tropsch Step**
  - No wax produced
  - Drop in gasoline, diesel and jet
  - Integrated Trailing reactor to totally convert all wax
  - High Conversion per pass
  - Excellent Heat transfer -mixing

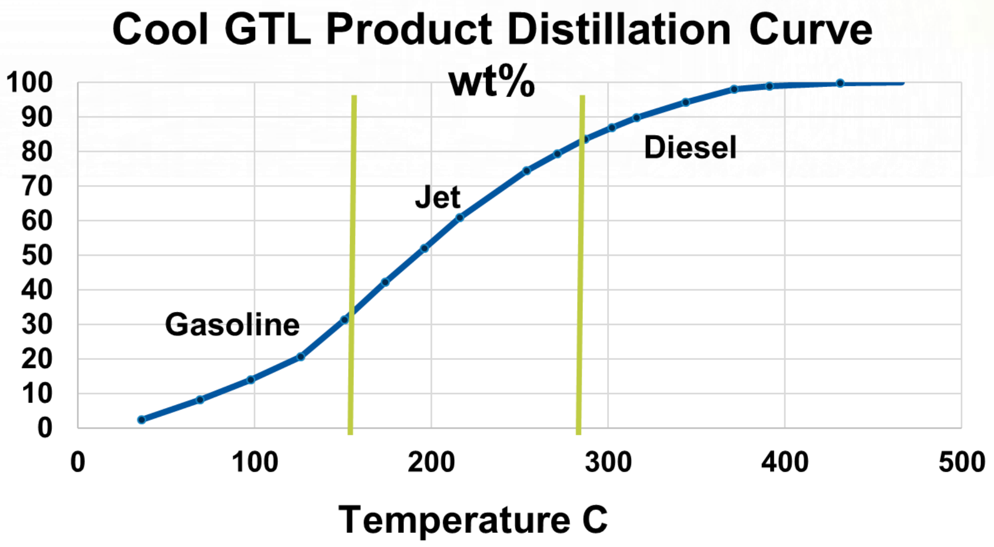
Low cost, simplified version of an old process.



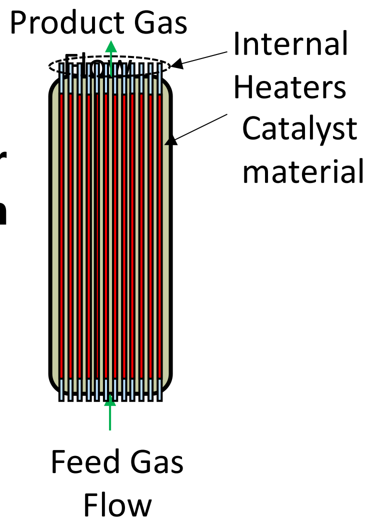
Clean Hydrocarbon Product

Cool GTL– High Quality Products





Electric reformer One reactor with internal heating elements



Why Combine Fischer Tropsch with Wax Cracking/Isomerization?

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- No Wax ! – Only make products you want
- Lower cost integrated system
- Similar to standard slurry FT reactor (Oryx GTL) except the wax is cracked and isomerized immediately
- Good heat transfer
- Easy scale up and scale down

Cool GTL® for the Production of Jet Fuel from Biogas Project

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- Main Goal – Make 100 gallons of high quality jet fuel (SAF)
- Utilizes Cool GTL small pilot unit using biogas feed
- Equally applicable to any biogas stream
- Will demonstrate Cool GTL Process and Stability
- Fully integrated and fully automated- round the clock operation

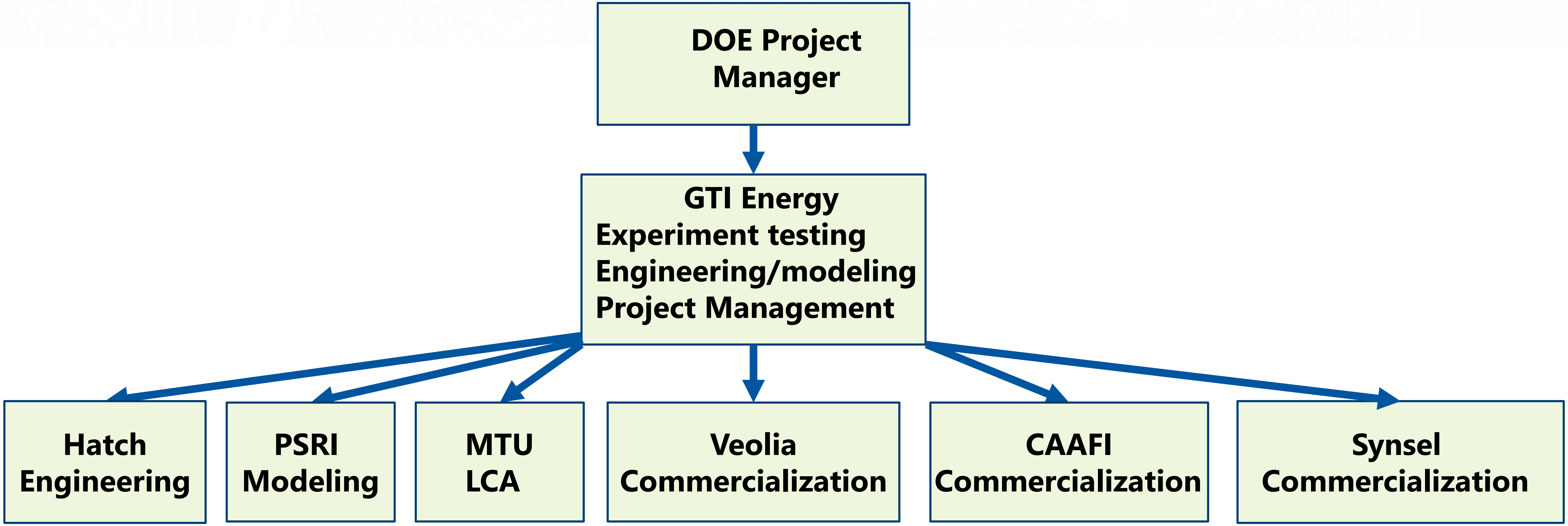
Overall Project Goals

1. Advance the Cool GTL technology development, as a simple cost effective gas-to-liquids (GTL) process for conversion of biogas
2. Show the technology is economically attractive (producing jet fuel at less than $3/GGE*) and reduces greenhouse gases by 65% compared to petroleum derived jet fuel
3. Integrate existing assets and unit operations into a continuous operable small pilot
4. Run in an integrated fashion using real biogas feed and make 100 gallons of high-quality biogenic jet fuel which passes jet fuel specifications
5. Experimentally verify that the Cool reforming can directly produce a 2:1 to 2.4:1 H_2/CO synthesis gas and that the Cool Fischer Tropsch (FT) section can achieve more than 60% carbon monoxide conversion per pass
6. Demonstrate catalyst stability for the Cool reforming process and Cool FT catalyst over a steady state pilot test campaign
7. Advance the Cool GTL technology from a Technology Readiness Level (TRL) of 3 to a TRL of 5

*- Gallons of Gasoline Equivalent

1 - APPROACH

Cool GTL PROJECT TEAM



Simplified Biogas to Jet Fuel Timeline

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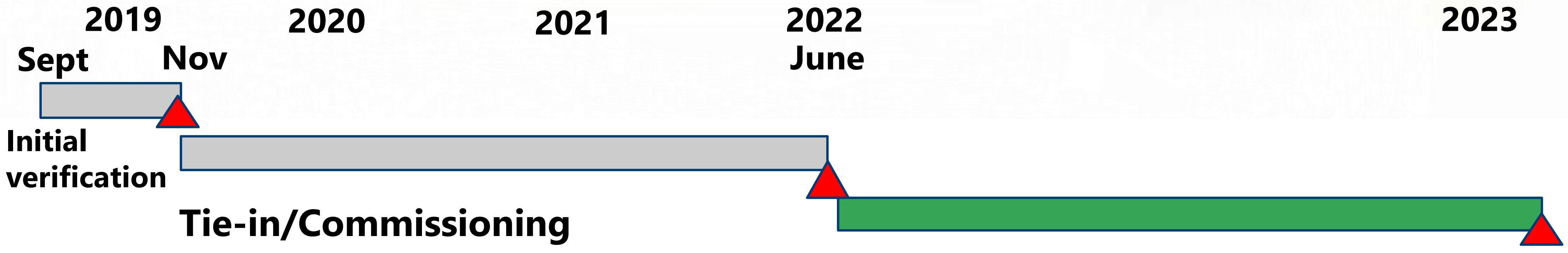

Tie-in/Commissioning
Shakedown
FT modeling and design
Produce 5 Gallons of Jet Fuel
Jet Fuel work up/analysis
Preliminary Engineering
Preliminary Technoeconomics (TEA)
Preliminary Life cycle analysis (LCA)

Produce 100 Gallons of Jet Fuel
Jet Fuel work up
Final Engineering
Final TEA
Final LCA
Final report

Go/NoGo Decision point
Completed
Future

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Potential Risks for the Project

1. Risk of heater burnout with electric reformer - Moderate
2. Risk of coking or catalyst deactivation with reformer feed containing CO, CO2 methane ethane and propane. - Moderate
3. Risk of poor quality jet product from Fischer Tropsch liquids - Low
4. Risk of poor selectivity in Fischer Tropsch- too much light ends, methane - Moderate
5. Risk of wax production from Fischer Tropsch - Moderate
6. Risk of poor economics (high capital or operating costs) cannot make jet fuel for <$3/GGE - Moderate

2 - PROGRESS AND OUTCOMES

Cool GTL – Pilot Plant- Panoramic View

Cool GTL Pilot Plant – Control Room and Product Recovery

Key Milestones

Completed Milestones

1. Initial verification on lab scale unit
2. Integration and shakedown of the Cool GTL unit
3. Short term testing (5 gallons of Jet fuel product)
4. Product separation and analysis
5. Reactor modeling (PSRI)
6. Initial LCA (MTU)
7. Initial TEA (Hatch +GTI Engineering)
8. BP2 Verification

Remaining Milestones

1. 100 gallons of jet fuel production
2. Product separation and analysis
3. Final LCA
4. Final Engineering/TEA Study
5. Final report /Verification

Goals of BP 2 Verification test

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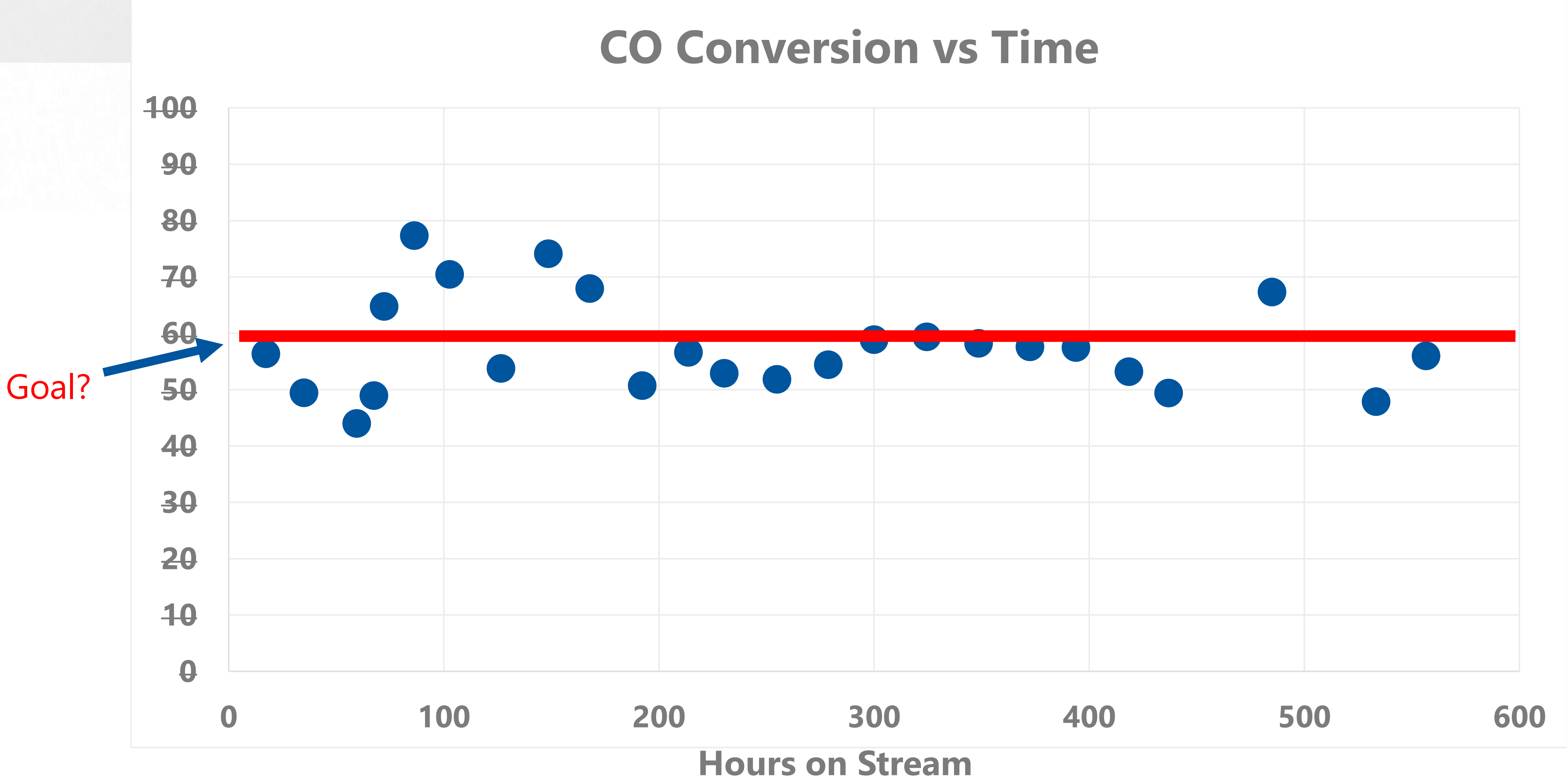
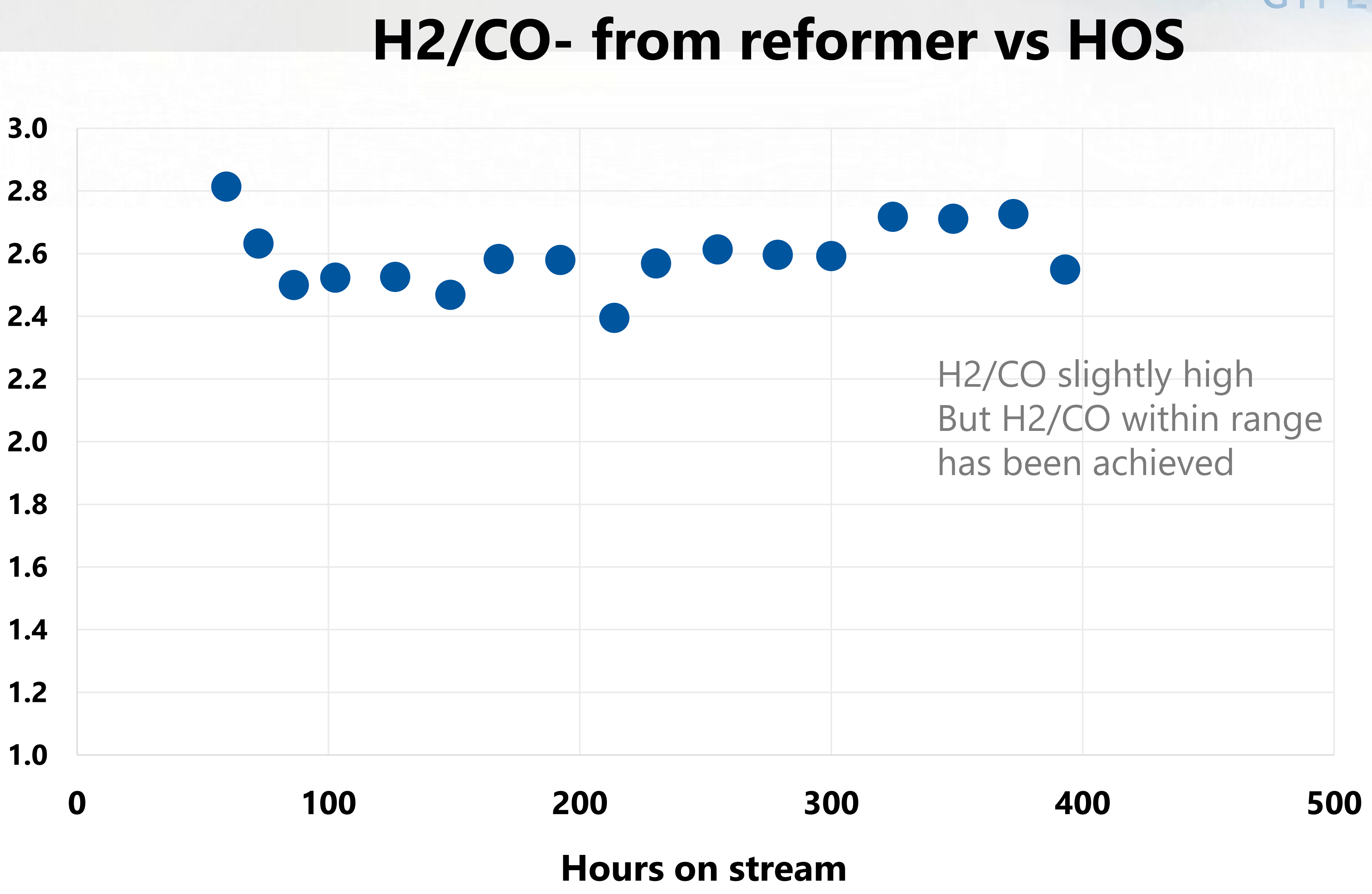
- Run Cool GTL System
  - make 5 gallons of high quality jet fuel
  - At 60% CO conversion on FT system
  - Reformer makes synthesis gas with 2.1-2.4 H2/CO ratio
  - Catalyst deactivation < 5C/200hours
- Initial Engineering/Technoeconomics show jet fuel can be produced at < $3.5/gal

FT liquids from Testing- 9+ Gallons

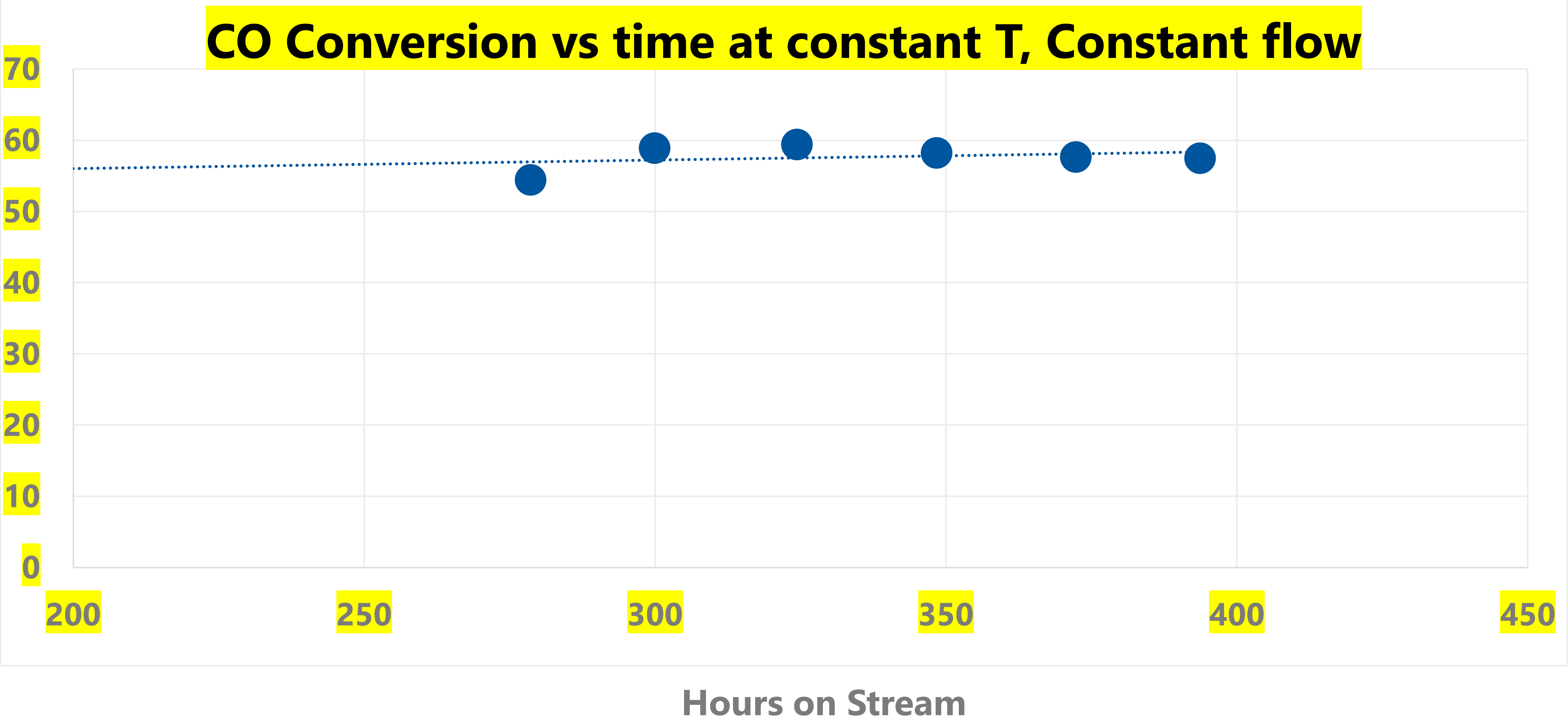
Initial Cool GTL Test Results



Initial Cool GTL Test Results



Initial Cool GTL Test Results
No Clear Deactivation Seen Yet



Integrated Testing to make 5 Gallons of Jet Fuel – Fractionation at Intertek

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	Wt%	Vol%	gallons	Density g/cc
Gasoline IBP-280C	38.14	40.77	4.4	.688
Jet 280-578C	53.39	51.82	5.5	.757
Diesel 578+C	8.47	7.42	.8	.839
Total	100	100	10.7	.735

5.5 gallons of Jet fuel made from 10.7 gallons of Total Liquid product

More diesel could have been put in jet fuel to increase % Jet fuel

High Quality Jet Fuel and Diesel Demonstrated

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- D86 distillation met all ASTM-7566 and ASTM-4054 jet fuel specifications except freeze point
  - Catalyst optimization currently in work to meet requirement
- Diesel Analysis

	analysis	Test
%C	83.86	D5291
%H	14.94	D5291
%O	1.1	D5291
Density	.806	D4025
Cetane index	74	D976

Preliminary Cool GTL Techno-economics (based on fired heater, stick built)

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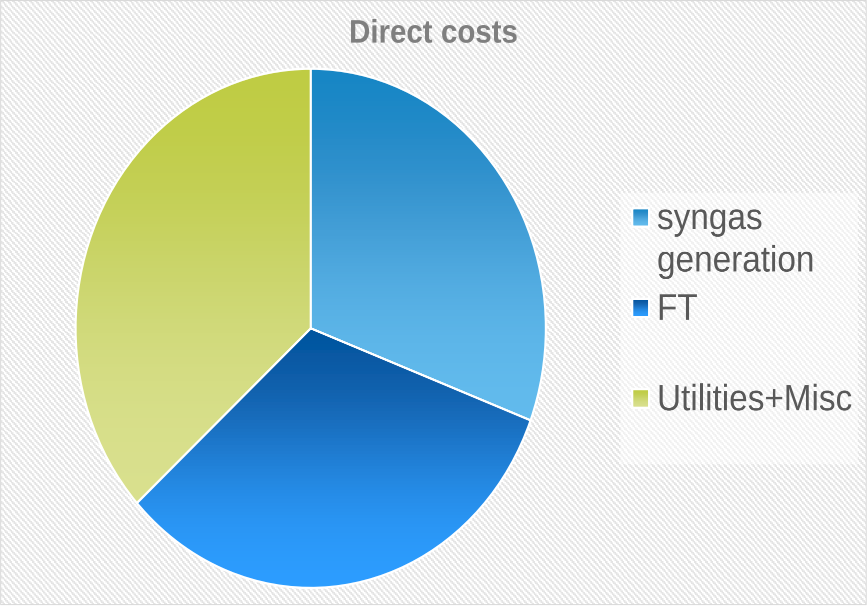
	IH2 Biogas	Digestor Biogas
Feed gas composition	Methane, ethane, propane, CO_2,CO,H_2	Methane, CO_2
Size Million ft3/d feed gas	7	1
Size bbl/d product	818	132
Size Million gal/yr product	11.9	1.9
Total Installed Capital Cost $Million	180	66
Breakeven $/gallon (no RINS)	3.2	6.2
Breakeven $/gallon(with RINS)	2.2	5.2

Future improvement- electric reformer, modular systems

Overall Capital Costs, in Millions

	IH2 Biogas	Digestor Biogas
Direct cost	112.7	38.7
Indirect Cost	25.8	11,9
Direct + indirect	138.5	50.6
Contingency (30%)	41,6	15.2
Overall costs	180.1	65.8

Direct Equipment Costs % each Category



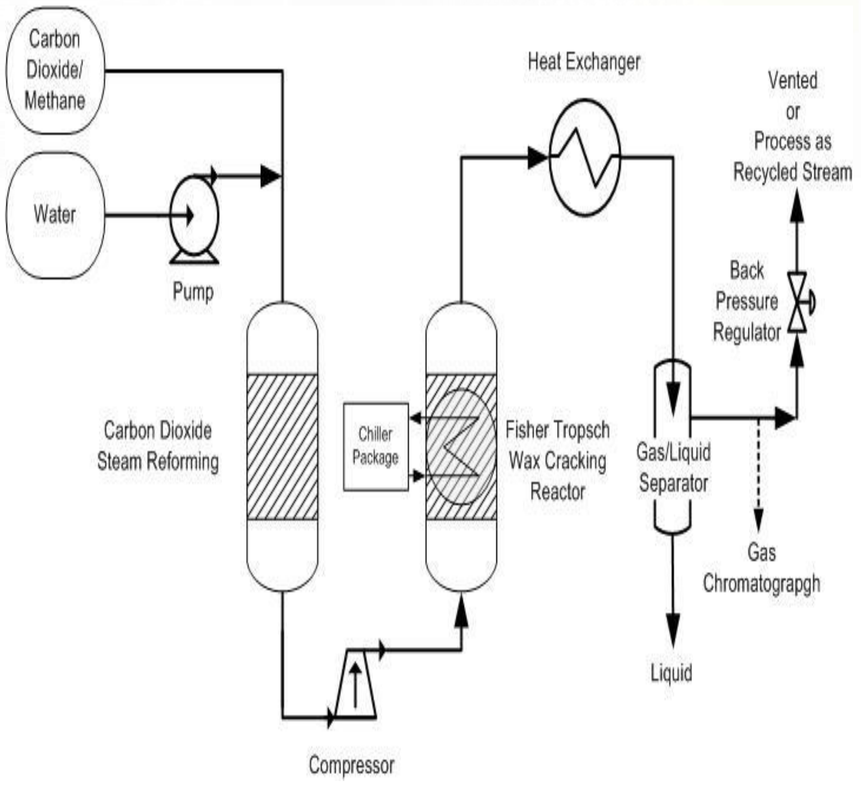
Preliminary LCA analysis in g CO2 equivalent/MJ Fuel

Cases	Biogas Case 1		IH² Case 2		
Item	Default	Renewable Electricity	Default	Renewable Hydrogen	Renewable Hydrogen + Electricity
Feedstock	-350.4	-350.4	84.0	30.2	26.6
Hydrogen	0	0	0	0	0
Power	10	0.9	3.4	3.4	0.3
Water	0.006	0.006	0.003	0.003	0.003
Catalyst	0.5	0.5	0.3	0.3	0.3
SulfaTrap	1.1	1.1	0.7	0.7	0.7
Total	-338.8	-348.0	88.4	34.6	27.9
% Reduction from Fossil Fuels	473%	483%	3%	62%	69%

IMPACT

100 gal/d Demonstration unit planned for GTI

- Reducing cost of small GTL is key to implementation of biogas GTL technology
- GTI has joined with a new commercial entity to commercialize the Cool GTL technology quickly
- GTI/Zeton is already engineering and building the next size Cool GTL demonstration unit of 100gal/day
- The goal is multiple Cool GTL units commercially deployed in 10 years



SUMMARY
Cool GTL for the Production of Jet Fuel from Biogas

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- Cool GTL process worked well and more than 5 gallons of high quality jet fuel produced
- Initial engineering shows <$3.5/gal SAF
- Initial LCA looks good
- Longer testing planned to make 100gal of jet fuel in BP3

Quad Chart Overview

Cool GTL for the Production of Jet Fuel EE0008507

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Timeline

- *Oct 2019*
- *Dec 2023*

	FY22 Costed	Total Award
DOE Funding	0.90 Million	2.99 Million
Project Cost Share *	20%	20%

TRL at Project Start: 3
TRL at Project End: 5

Project Goal

Low Cost streamlined GTL process

SAF at <$3.0gal from biogas

End of Project Milestone

- Make 100gal of high quality SAF from biogas
- Show TEA for SAF through this pathway

Funding Mechanism

DE-FOA-1926, TA1 (2018)

Project Partners

- Hatch , MTU, PSRI, CAAFI, Veolia, Synsel

Cool GTL Related Patents

- **Current CoolGTL configuration is based on prior art – no new patents have come from this project yet**

BACKUP INFORMATION

Cool GTL Reactions

(I) $H_2O+CH_4 \rightarrow CO+3H_2$	CO and H_2 formation (800^oC)	Reactor 1
(II) $CO_2+CH_4 \rightarrow 2CO+2H_2$	CO and H_2 formation (800^oC)	Reactor 1
(III) $CO_2+H_2 \rightarrow H_2O+CO$	Water-gas shift to equilibrium	Reactor 1
(IV) $CO+2H_2 \rightarrow -[CH_2]-+H_2O$	Hydro/oligomerization (200^oC)	Reactor 2
(V) $H_2+-[CH_2]- \rightarrow -[CH_2]-+H_2$	Isomerization (200^oC)	Reactor 2