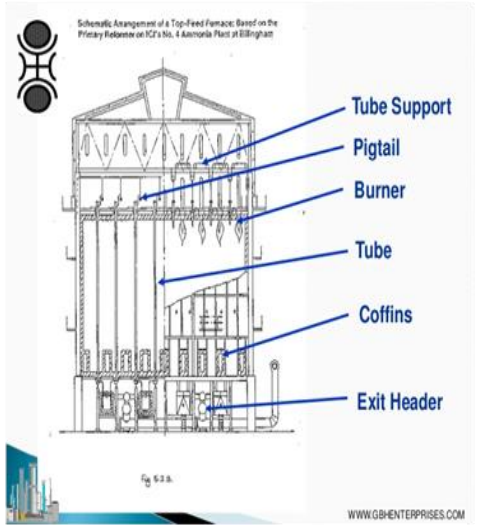
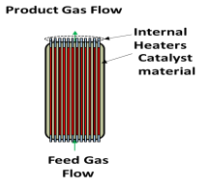
DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Typical Commercial Scale Stream Methane Reformer



GTI's Electric Reformer Design with Internal Heating Elements



Low Cost
Small Footprint
No CO2

Novel Electric Reformer for Drop In Fuels from Biogas or Waste CO2

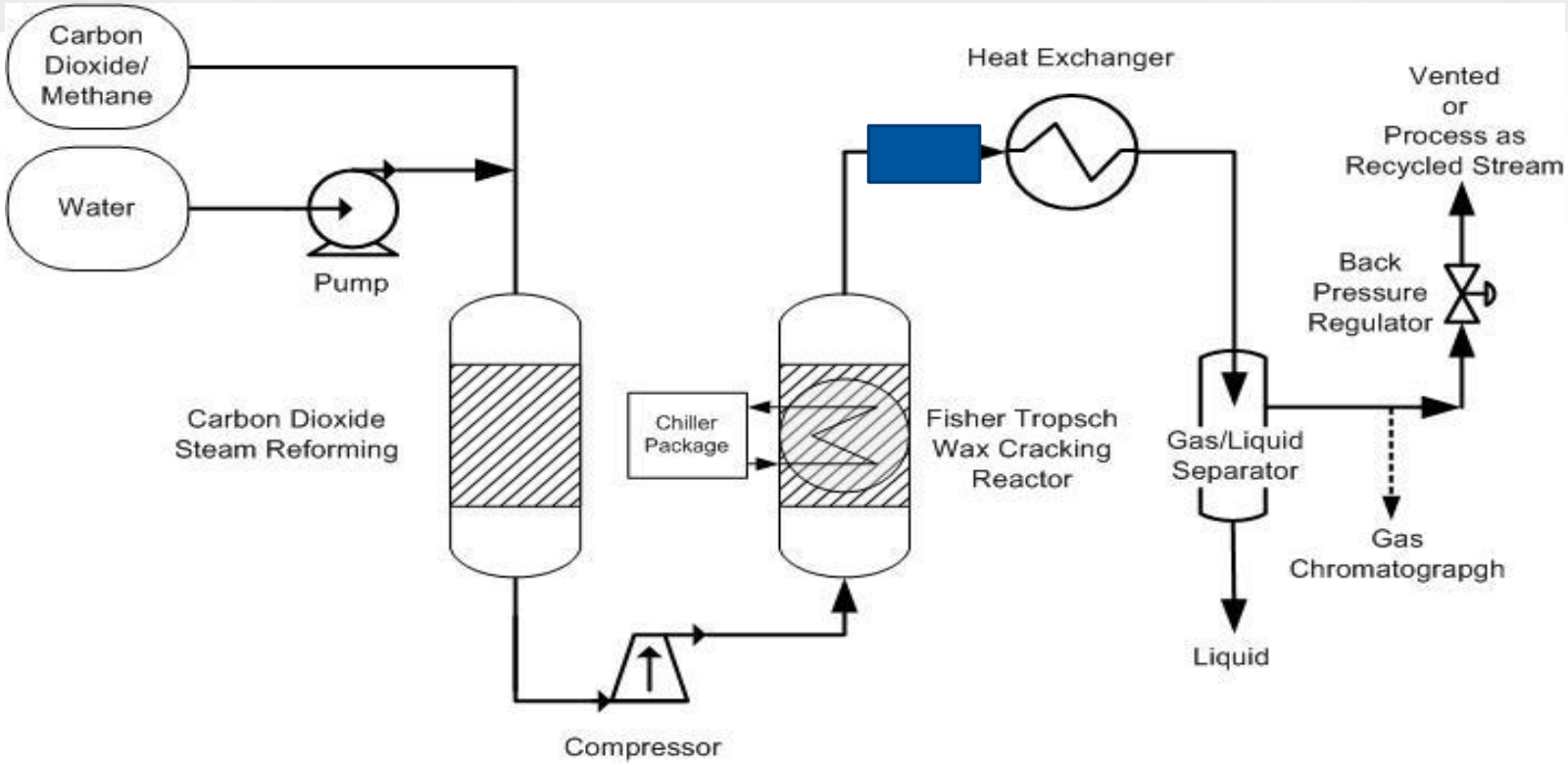
FOA-EE0002396 WBS 3.5.2.701

April 4, 2023
Principal Investigator Terry Marker
Project Manager Megan Herrera

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

Unique Cool GTL Technology

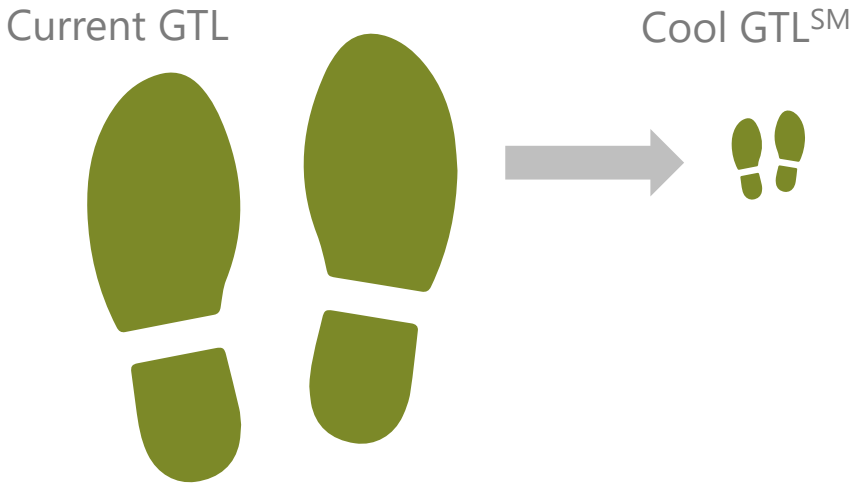
Novel Features

- Unique bi-reforming catalyst
- Unique wax cracking-FT catalyst
- Unique electric reformer design

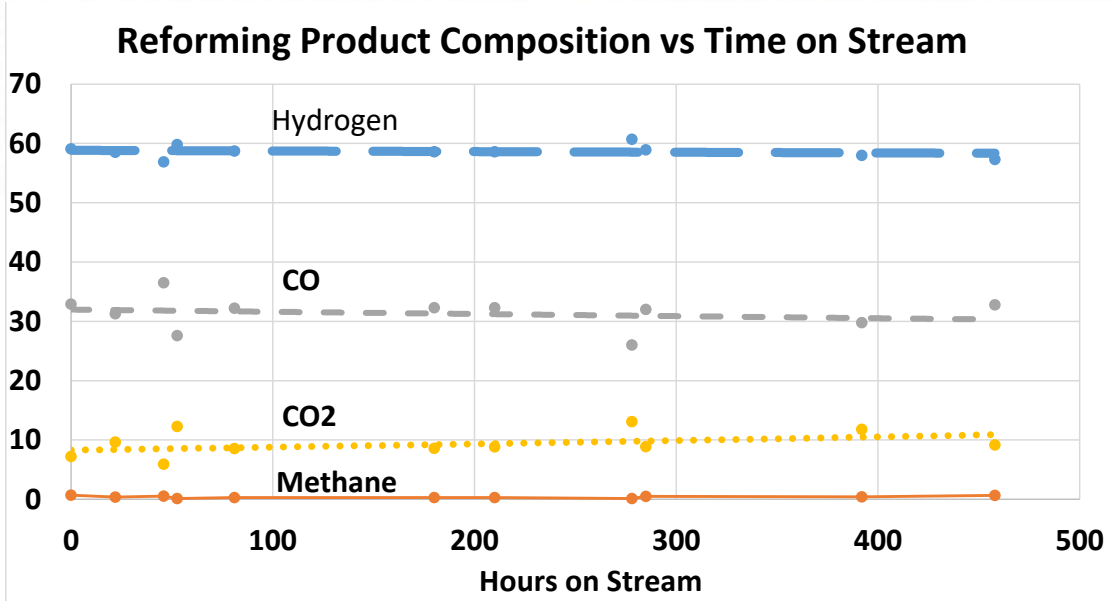
Four patents issued and several others pending

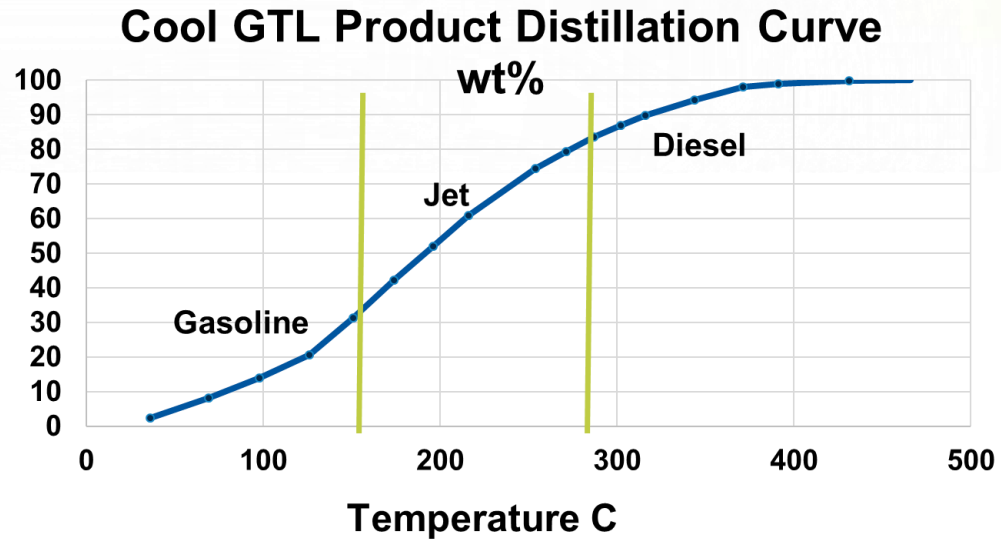
Beneficial Results

- Modular, low-cost GTL
- Small footprint
- Great economics
- Distributed plant locations

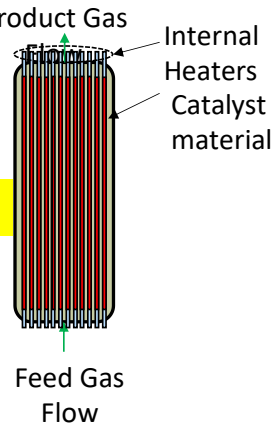


Cool GTL– High Quality Products





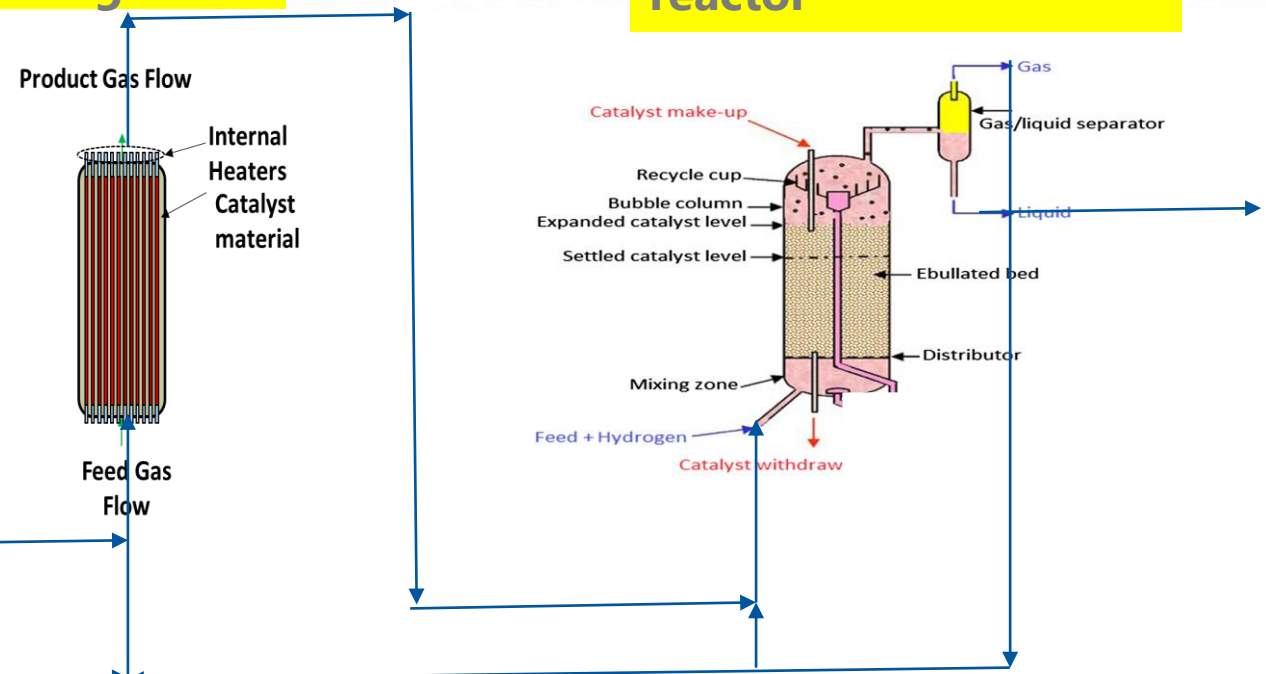
Electric reformer One reactor with internal heating elements



Cool GTL – With Electric Reformer and Slurry bed

Electric Reformer or Reverse water gas shift

Fischer Tropsch Slurry reactor



Jet, Diesel and Gasoline

CO2 +H2

or

Biogas+H2O

Electric reformer is first stage of Cool GTL

Novel Electric Reformer for Drop In Fuels from Biogas or Waste CO2
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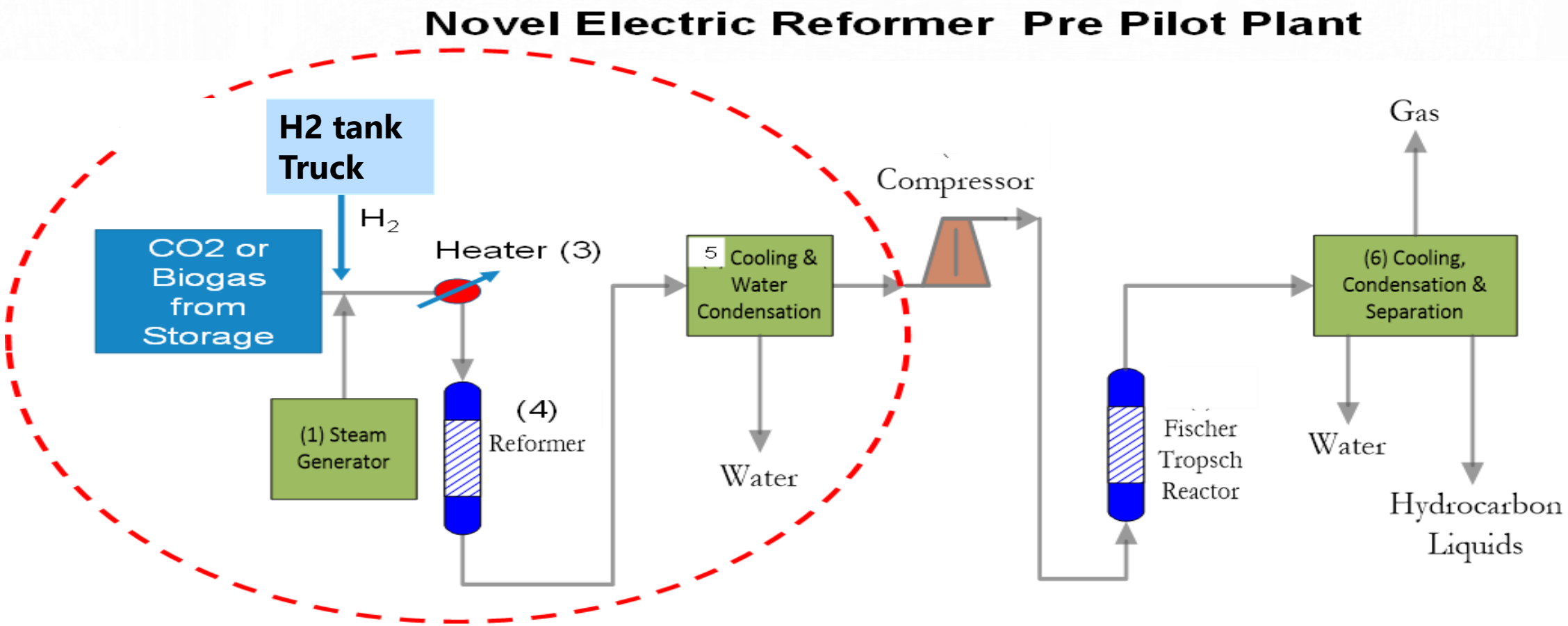


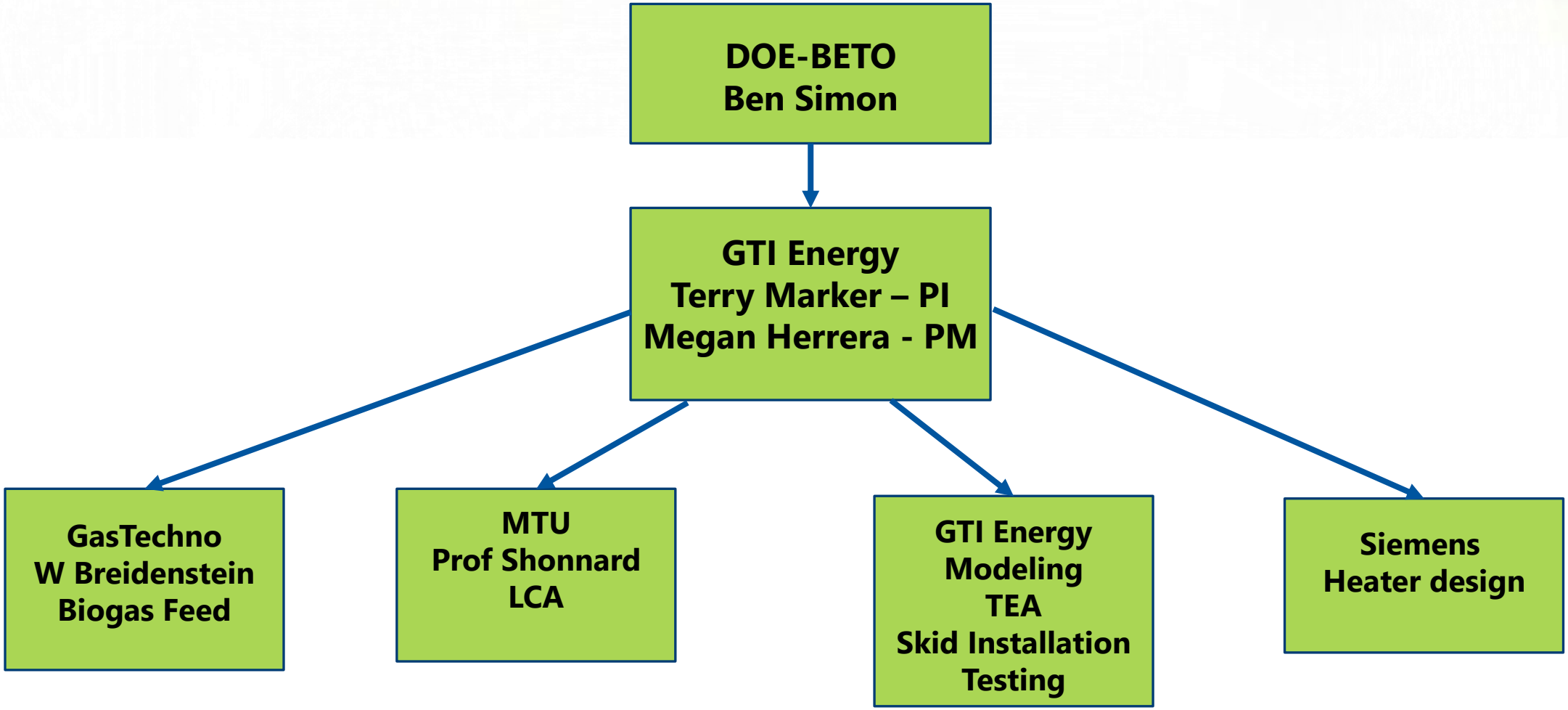
Goals - Novel Electric Reformer for Drop In Fuels from Biogas or Waste CO2

- **Main Goal – Scale up Electric reformer from existing 1kg/hr feed size to 100kg/hr size (makes 100gal/day of liquid product)**
- **Develop fundamental models of the electric reformer which can be used for scale up to commercial size**
- **Build and shakedown Electric reformer pilot plant**
- **Test the scaled up electric reformer with biogas and CO2 + H2 gas for 500 hours (250 hours with each feed)**
- **Complete Life Cycle Analysis (LCA)**
- **Complete Techno-economics (TEA) to make jet fuel for less than $2.75/GGE* using electric reformer and Cool GTL**

* - GGE Gallons of Gasoline Equivalent

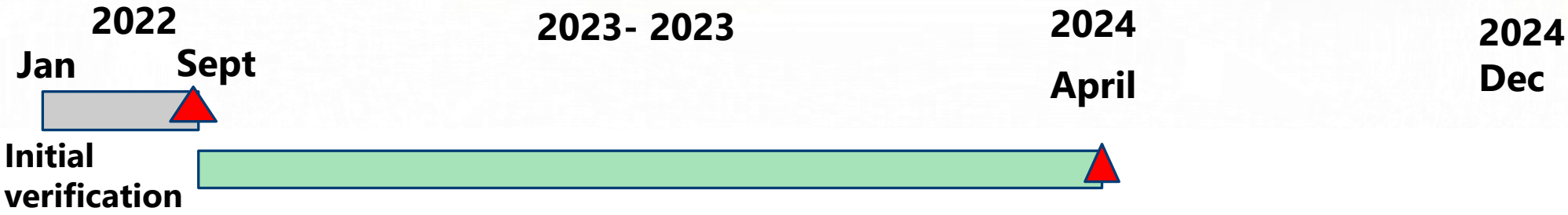
APPROACH

Electric Reformer – Project Partners



Zeton is important vendor building Pilot plant

Simplified Electric Reformer Timeline



Model Electric reformer
Design and Build larger electric reformer
Test electric reformer with Biogas and CO_2 +H_2 gas
Preliminary Engineering
Preliminary TEA
Preliminary LCA

Final LCA
Final TEA
Final report

Potential Project Risks

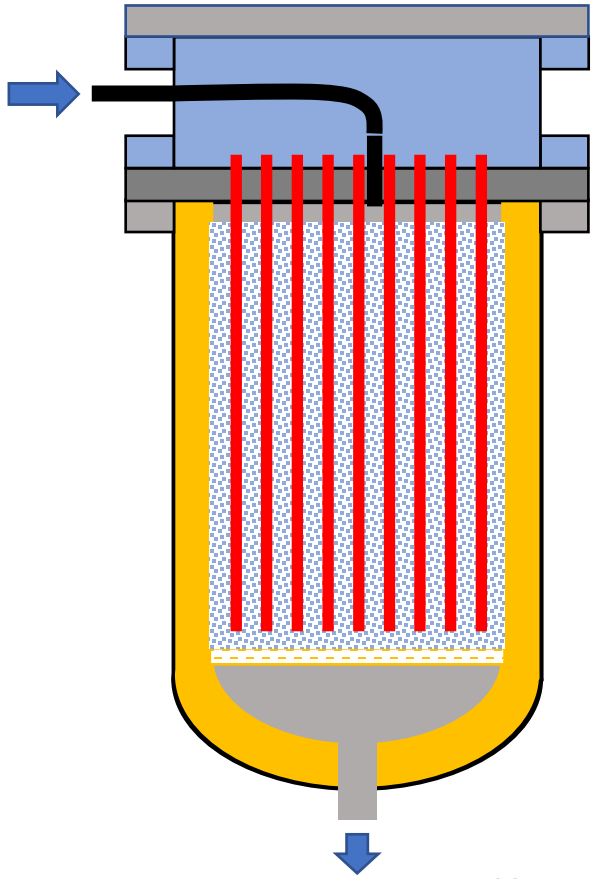
- Risk of heater burnout with electric reformer – Lessons learned from bench scale unit incorporated into design and control strategy for this unit
- Risk of coking or catalyst deactivation with reformer feed containing CO, CO2 and methane – >500 hours completed in bench scale unit without deactivation
- Risk that model does not predict performance – models anchored to bench scale unit
- Risk of poor economics (high capital or operating costs) cannot make jet fuel for <$2.75/GGE - preliminary TEA projects $2.75/GGE, to be updated in BP3 with updated performance data and process flow sheet

PROGRESS AND OUTCOMES

Significant Scale-up from Successful Bench Scale Tests

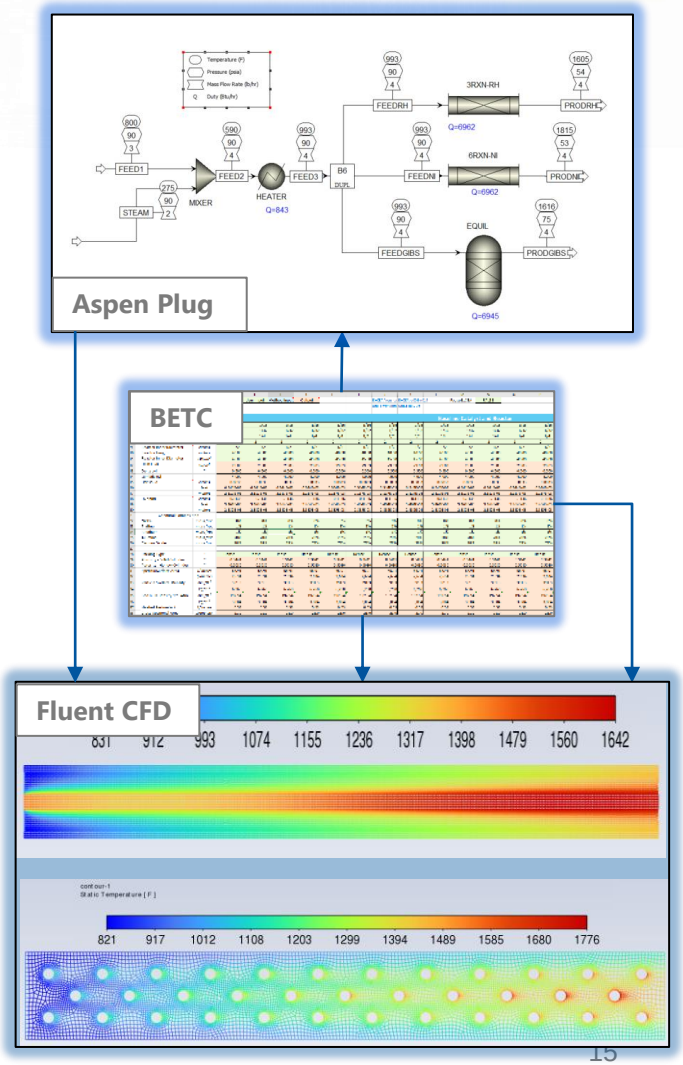
1 kg/hr bench scale unit

100 kg/hr pilot scale unit to be designed and tested in the current project



Modeling Efforts

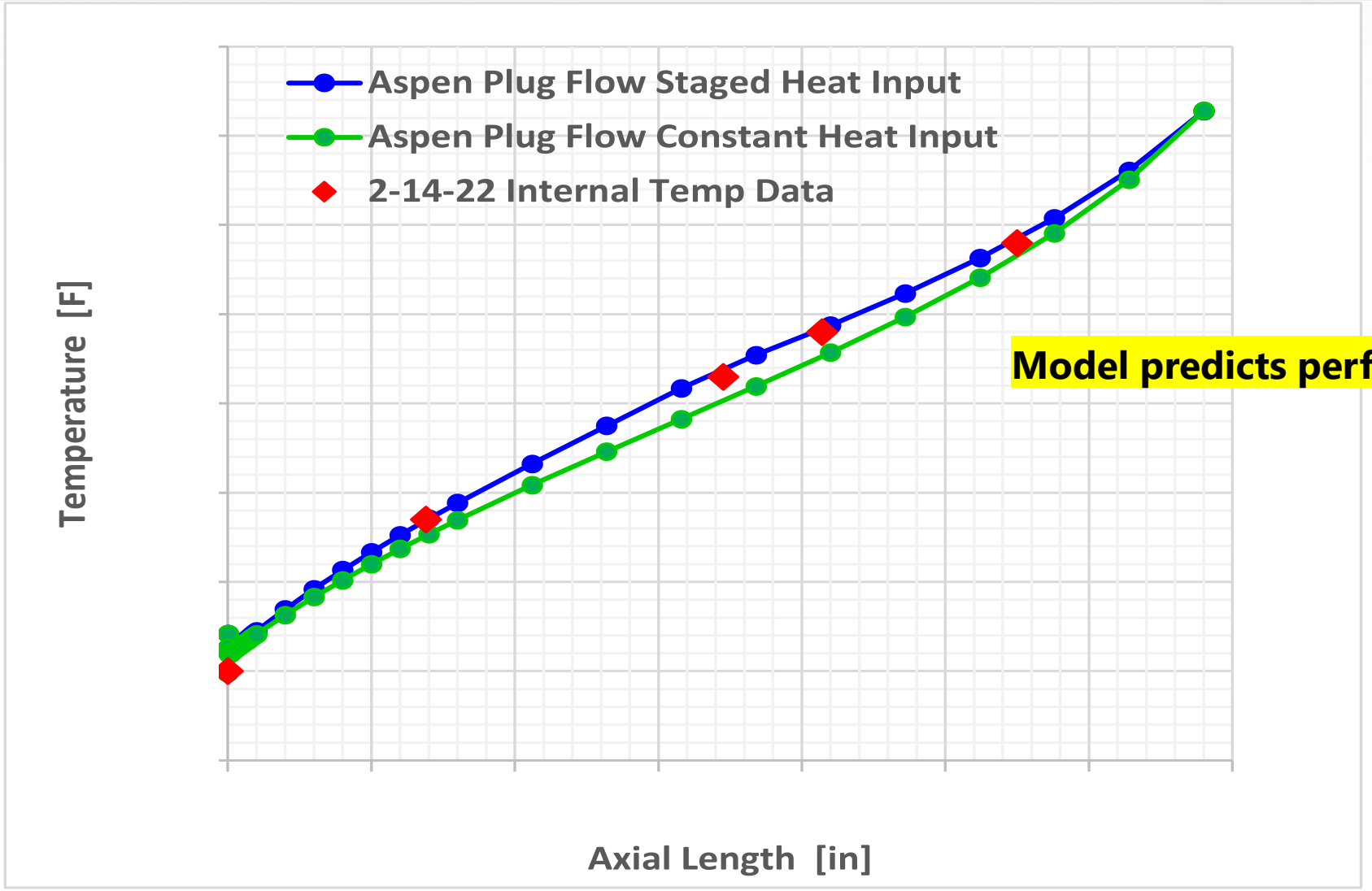
- **CFD, particle bed and AspenPlus plug flow models developed**
  - –AspenPlus for rapid parametric studies to refine design space
  - –Particle bed equivalent thermal conductivity model (BETC) generates bed properties
  - –CFD yields radial temperature and composition gradients
- **Reforming catalytic kinetics included**
  - –Literature data with similar catalysts available
- **Use CFD results to determine spacing of heating elements and size of reactor**
  - –Maintain process gas temperature within target conversion ranges
- **Anchored to lab scale test data**



Test Rig Instrumented for Model Anchoring

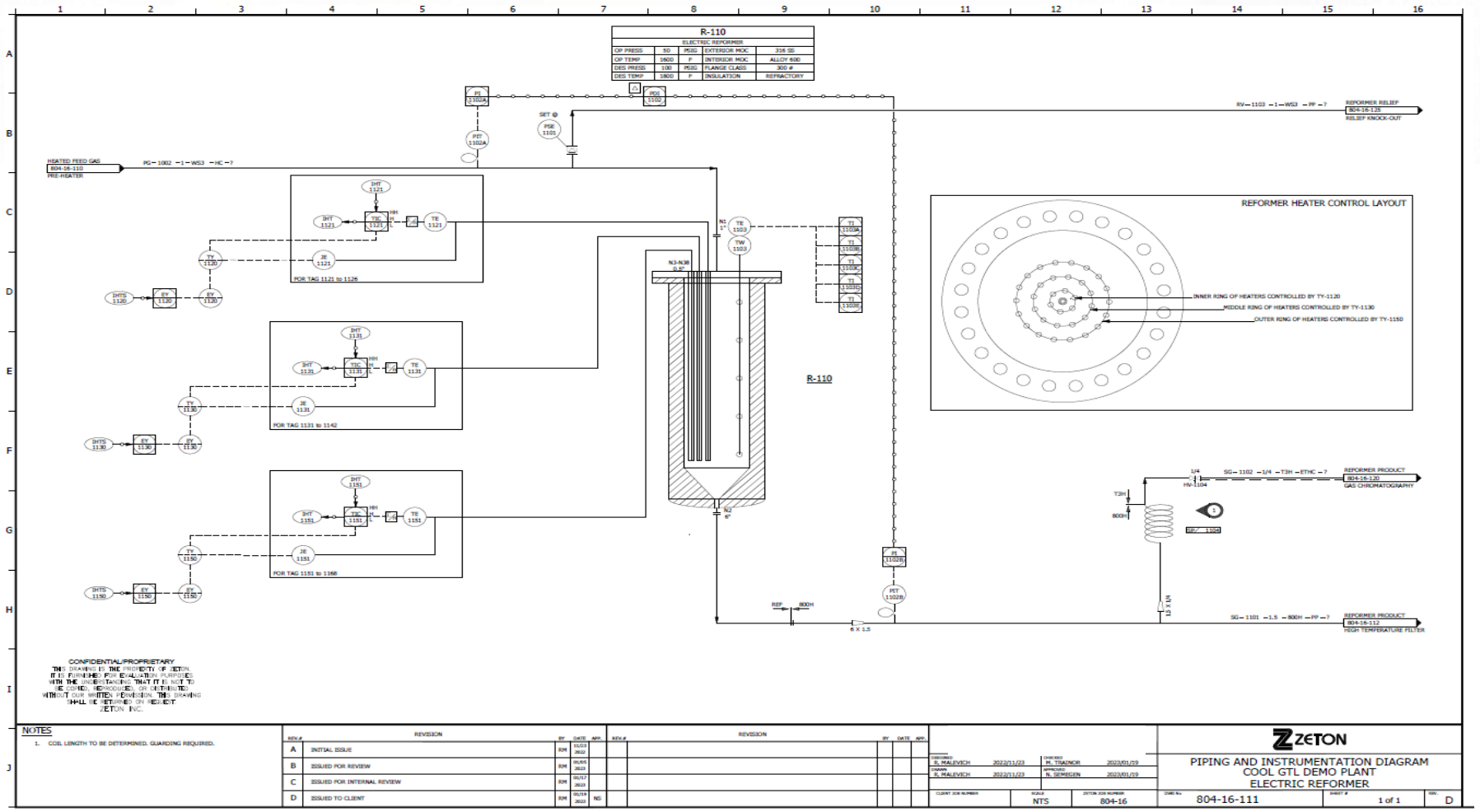
- **Temperatures**
  - –Six internal heater temperatures
    - Between heating element and sheath
  - –Process gas inlet temperature
  - –Four internal process gas temperatures
  - –Two/four external vessel skin temperatures
- **Pressure drop through vessel**
- **Composition**
  - –Process gas inlet composition
  - –Four GC tapoff locations axially plus exit composition
- **Heater outputs**
  - –Lower & upper

Electric Reformer Modeling Predictions versus Experimental Data



Model predicts performance well

E-Reformer Section P&ID Diagram -



Electric reformer P&ID Completed

Key Milestones

Completed Milestones

1. ✓ Initial verification on lab scale unit
2. ✓ Modeling of Electric reformer
3. ✓ Design of Electric reformer pilot plant with Zeton

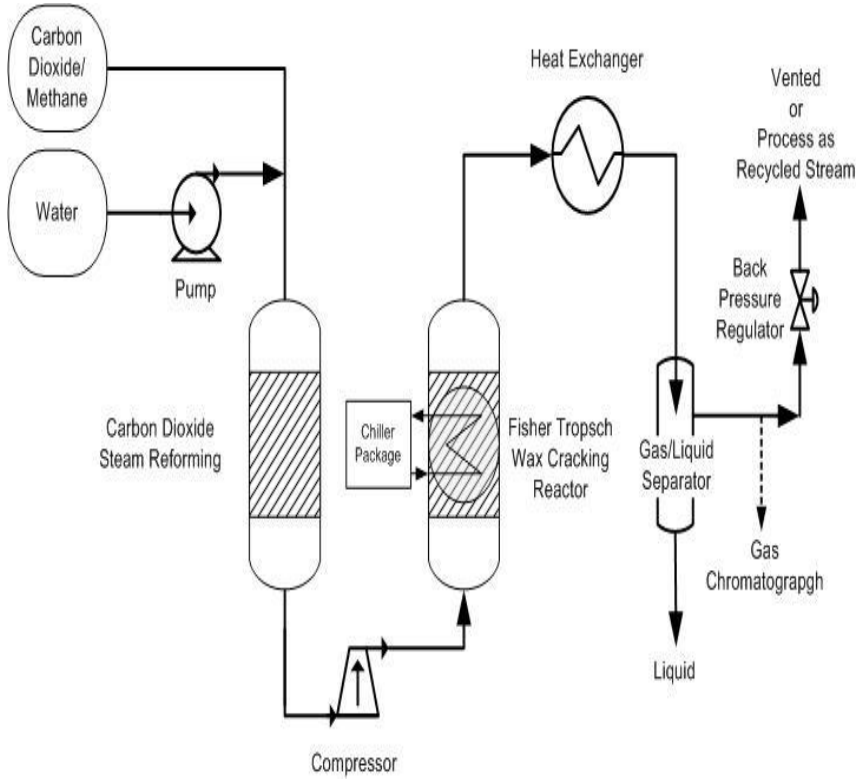
Remaining Milestones

1. Detailed Engineering and build of Electric reformer Pilot plant
2. Installation and shakedown electric reformer Pilot plant
3. Test electric reformer pilot plant with CO_2+H_2 feed and biogas feed
4. Intermediate Verification
5. LCA
6. TEA- Jet fuel less than $2.75/gal
7. Final report /Verification

IMPACT

- **Reducing cost of small GTL is key to implementation of biogas GTL technology**
- **GTI has joined with a 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**

100 gal/d Demonstration unit planned for GTI



SUMMARY

- Initial Verification Complete, currently in BP2
- Electric reformer modeling completed
- Electric reformer pilot plant in design and will be constructed this year
- Testing planned for early next year
- Quick Tie-in to FT section planned once electric reformer testing completed

Quad Chart Overview

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Timeline

- *Jan 2022*
- *Dec 2024*

	FY22 Costed	Total Award
DOE Funding	$161,500	4.0 Million
Project Cost Share *	20%	20%

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

Project Goal

Small size , low cost, low emissions Electric Reformer modeled, designed and tested

SAF at <$2.75 gal from biogas or CO2+H2

End of Project Milestone

- Working 100kg/hr. electric reformer which makes syngas from biogas or CO2+H2
- SAF at < $2.75/gal from biogas

Funding Mechanism

DE-EE0002396.

Project Partners

- MTU, GasTechno, Siemens

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E-Reformer Related Patents

Patent #	Date granted	Title	Covers
10,738,247	**8/11/2020**	Processes and systems for reforming of methane and light hydrocarbons to liquid hydrocarbon fuels	**Cool GTL which includes Cool reformer**
10,906,808	**2/2/2021**	Noble metal catalysts and processes for reforming of methane and other hydrocarbons	**Cool reforming catalyst**
11,111,142	**9/7/2021**	Processes and catalysts for reforming of impure methane-containing feeds	**Cool reforming process and catalyst**

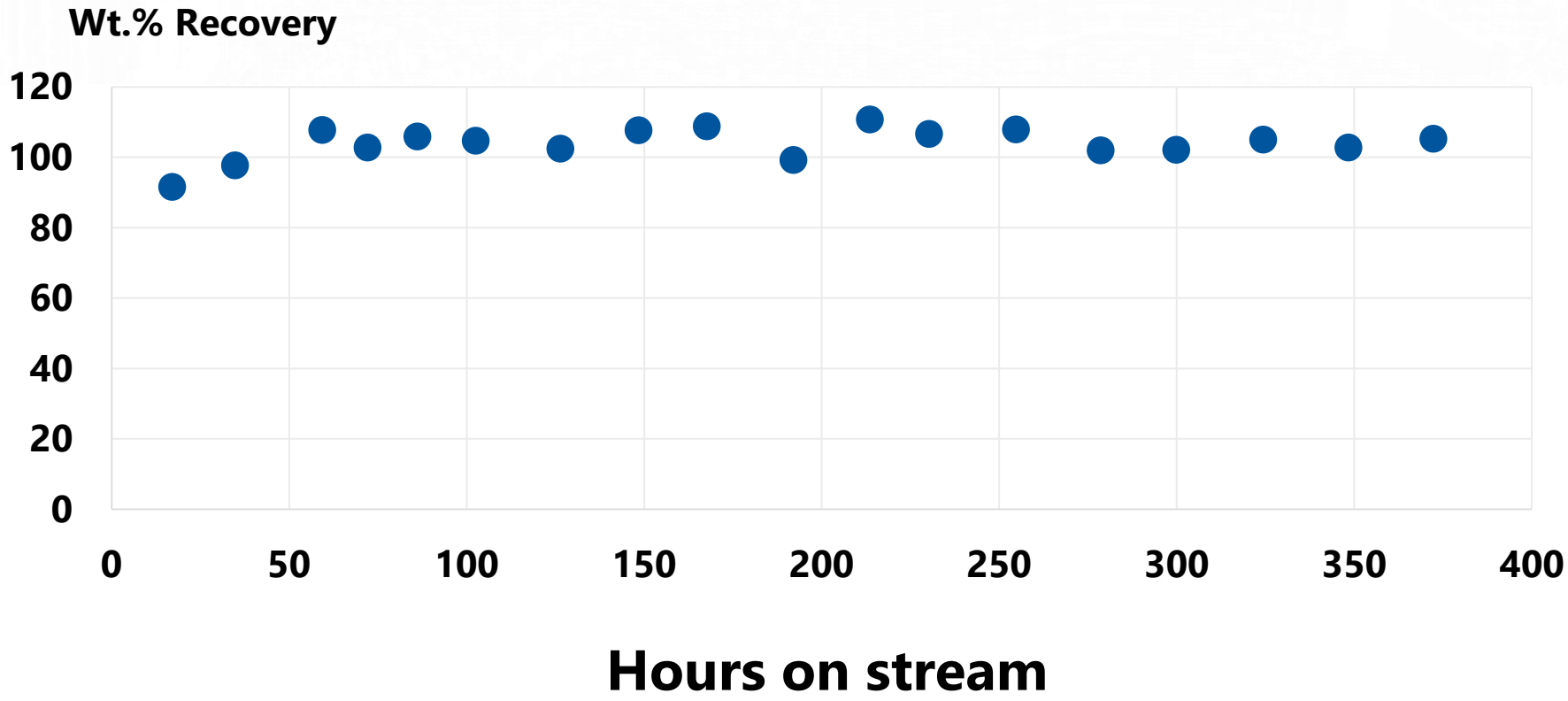
Electric reformer Patents filed but not yet issued
No patents derived from this project yet, but several are prior art to this project and related

GTI ENERGY

solutions that transform

BACKUP INFORMATION

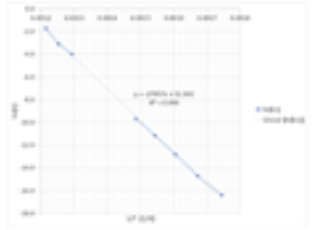
Electric Reformer Material Balance
1kg/hr. scale



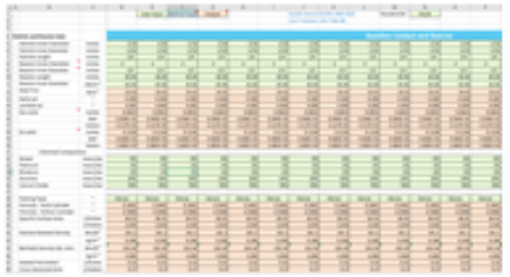
Electric Reformer Modeling

CoolGTL Hysys Model
- Heat duty, T, P, flowrate, composition

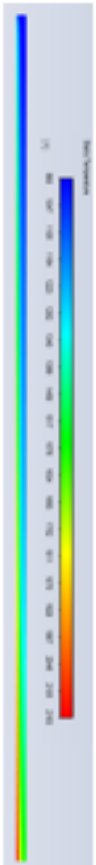
Kinetics Inputs
- Reaction rate equations
- Kinetics rate constants



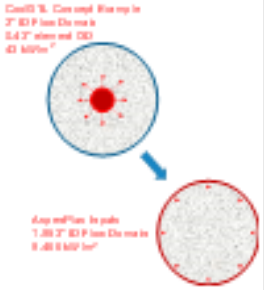
Catalyst Details to Define Bed Props.
-Density, Void, Conductivity



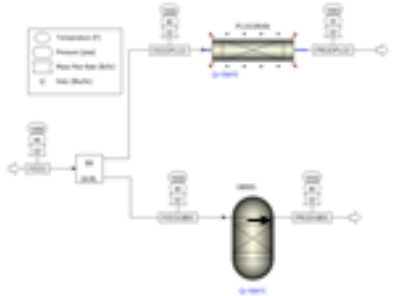
Fluent CFD Model
- Axial & Radial Gradients
- T, P, [X], Vsf, Reaction Rates, etc.



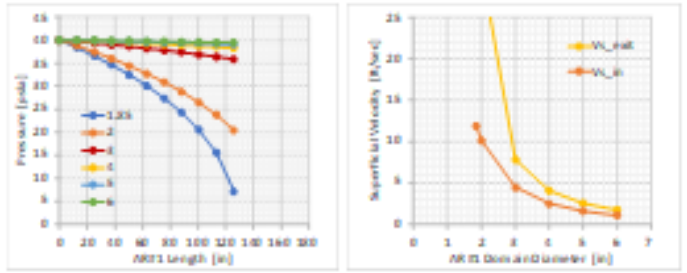
Heating Element Definition
- Element geometry, heat output
- Convert to AspenPlus configuration
  - Perimeter heated
  - Maintain total heat



AspenPlus Plug Flow Model



Model Output Trades and Profiles
- T, P, [X], Vsf, Reaction Rates, etc.



Cool GTL Reactions

(I) $H_2O+CH_4 \rightarrow CO+3H_2$	CO and H_2 formation (800°C)	Reactor 1
(II) $CO_2+CH_4 \rightarrow 2CO+2H_2$	CO and H_2 formation (800°C)	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°C)	Reactor 2
(V) $H_2+-[CH_2]- \rightarrow -[CH_2]-+H_2$	Isomerization (200°C)	Reactor 2