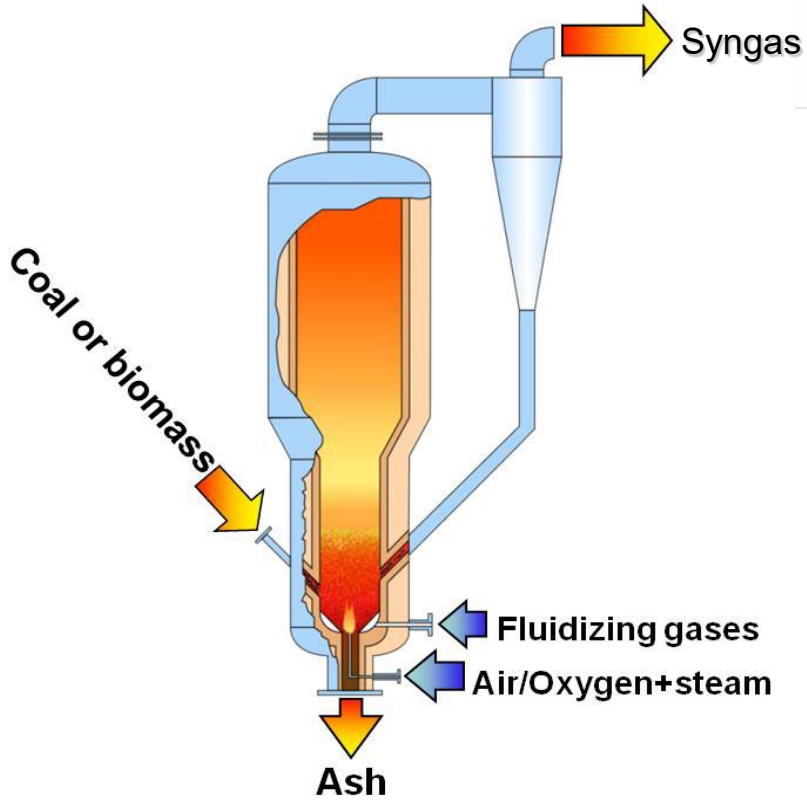
U-GAS ™ + Cool GTL™ - A New Integrated Process for Direct Biomass Conversion to Liquid

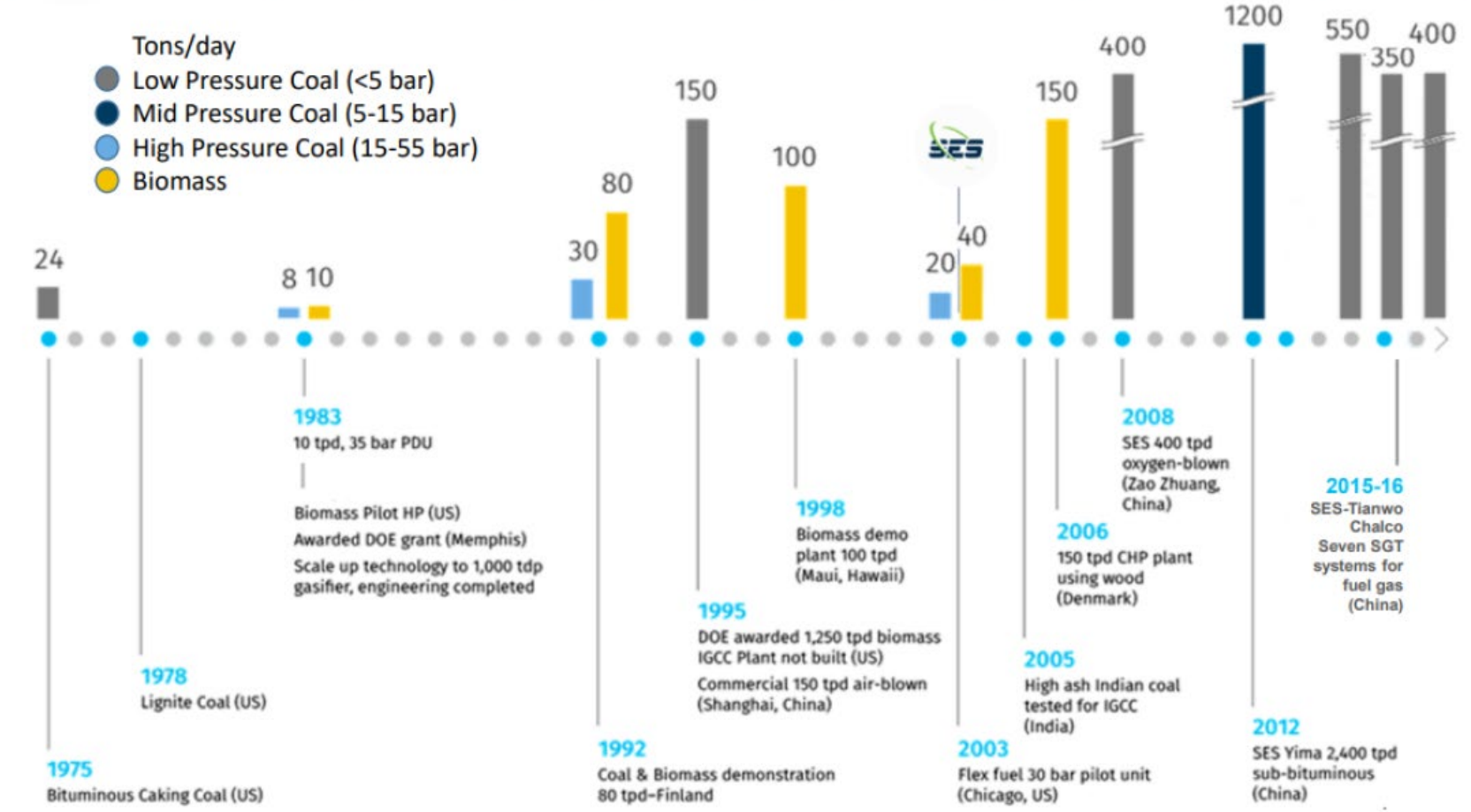
Zach El Zahab, PhD – Gasification Program Manager, GTI
Terry Marker, Senior Institute Engineer, Bioenergy Initiatives Manager, GTI

GTI Gasification Technology Platform - U-GAS®



- Single fluidized bed gasifier, simple and low-cost design
- High efficiency, up to 99% carbon conversion and 85% CGE & reliable operation
- Feedstock flexibility – all ranks of coal, biomass & wastes
- Operational flexibility – high and low pressure, air, enriched air or oxygen, high turn down, low or no tar and oil production
- Dry feed and discharge, low water usage & environmentally friendly
- Commercially deployed, 21 gasifiers in 7 plants

Commercial U-GAS® Coal Plant Capabilities



GTI Gasification Pilot, Demonstration and Commercial Demo Plants

80 ton per day Gasification Plant in Finland using biomass & coal

800 ton per day U-GAS® coal gasification plant in Shanghai, China

100 ton per day RENUGAS ® demo plant in Maui using bagasse

Advanced FlexFuel GasificationTest Facility Des Plaines, IL using wood and coal

150 ton per day CHP Plant in Skive, Denmark using wood

2 x 400 ton per day U-GAS® in Zao Zhuang City, China using coal

Additional Commercial Projects

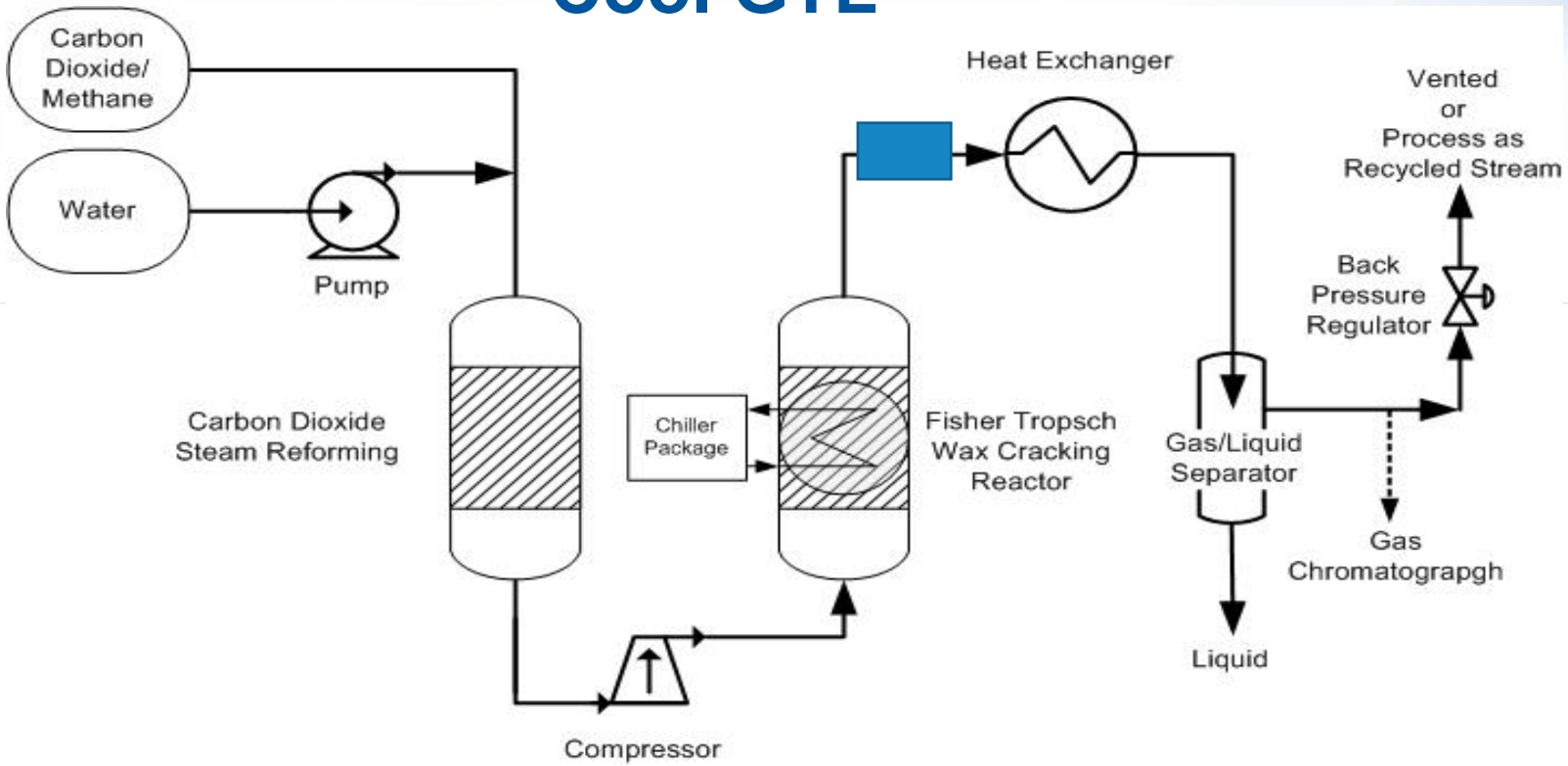
Site	No. of Gasifiers	Syngas Capacity (nm^3/hr)	Startup Year
Zaozhuang	2	20,000	2008
Yima	3	90,000	2012
Shandong	2	80,000	2015
Shanxi	1	26,000	2016
Henan	4	120,000	2016
Totals:	12	338,000	

ZZ 2008

Yima 2012

Chalco 2015-2016

Cool GTL

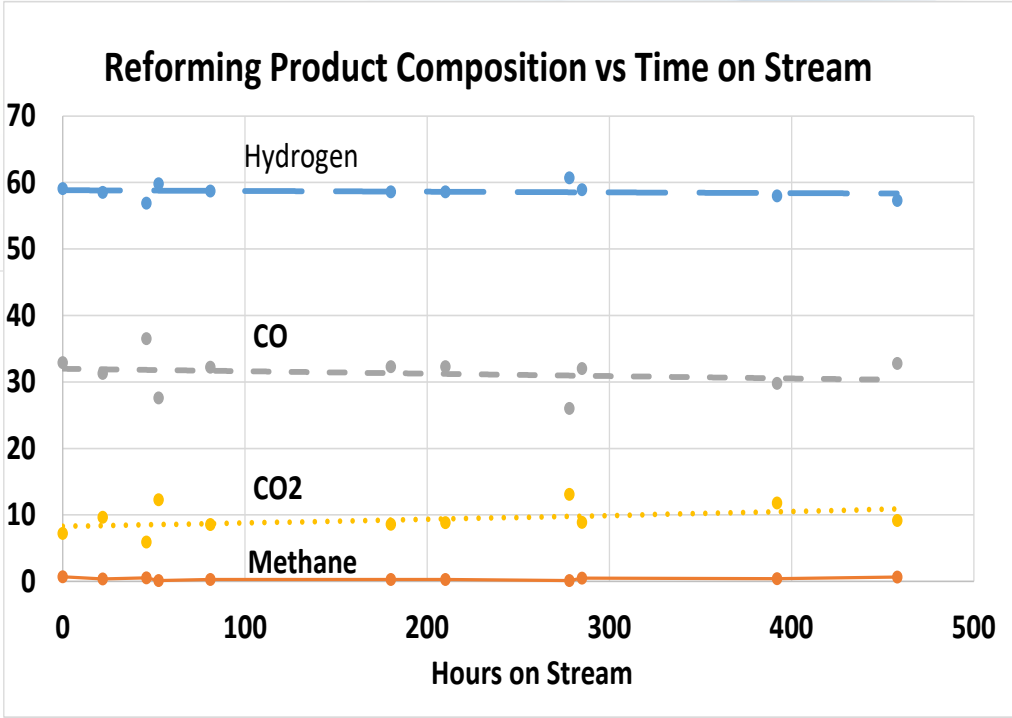


- Converts CO_2-rich methane, ethane and propane to high-quality gasoline, diesel and jet fuel
- Works well for any gas containing CO_2 or CO
- Uses unique CO_2/steam reforming catalyst to directly make 2:1 H_2/CO synthesis gas
- Uses unique combined Fischer-Tropsch and wax-cracking reactor
- Simple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

What's Unique and Different about Cool GTL?

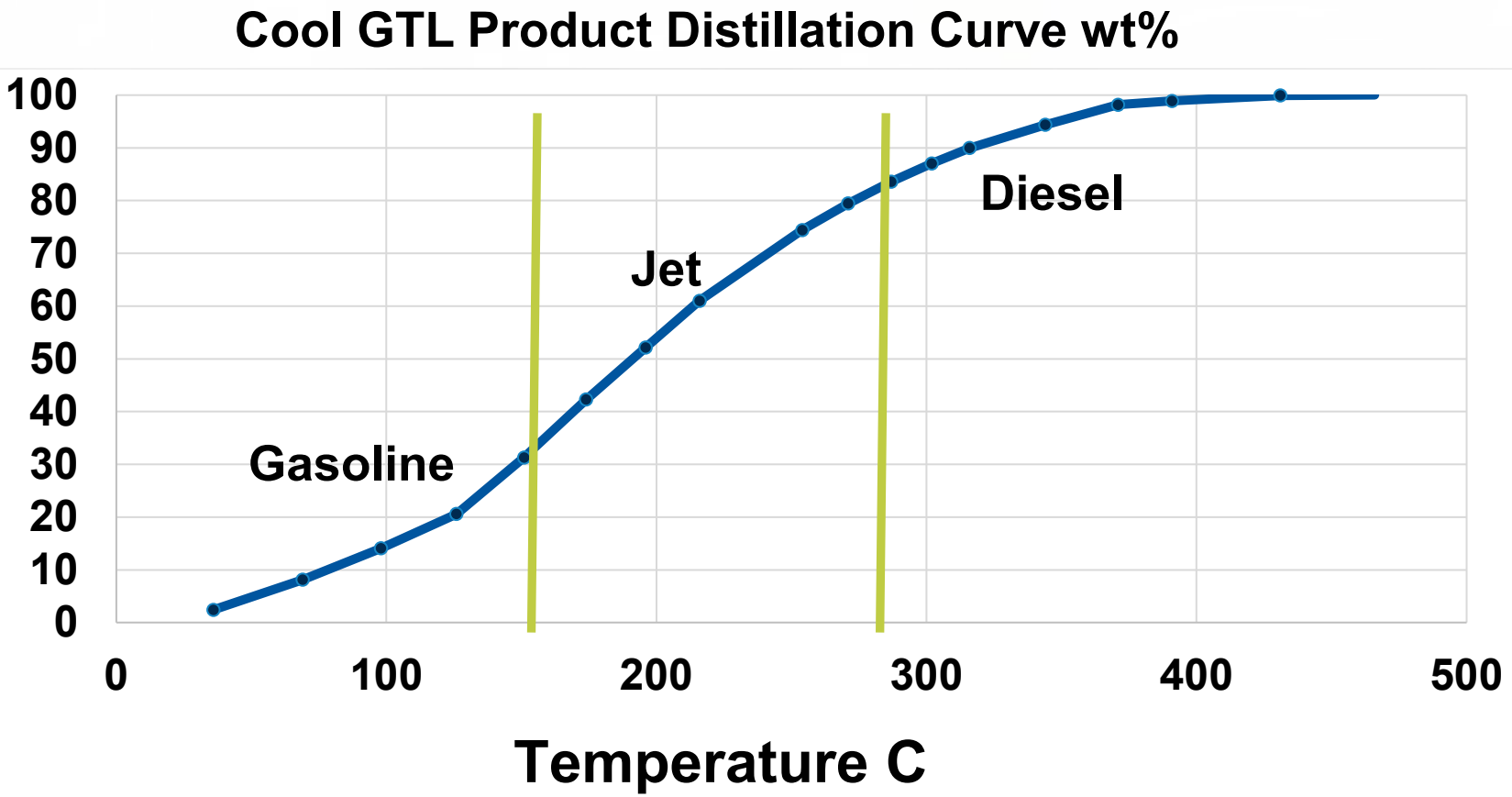
- Unique Catalyst in Cool Reforming Step
  - Robust with long life - minimal coking
  - Directly makes 2/1 H_2/CO synthesis gas by adjusting amount of steam added
  - Simple and direct, mild temperatures, steady performance
- Unique Catalyst in Fischer-Tropsch Step
  - No wax produced
  - Drop in gasoline, 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

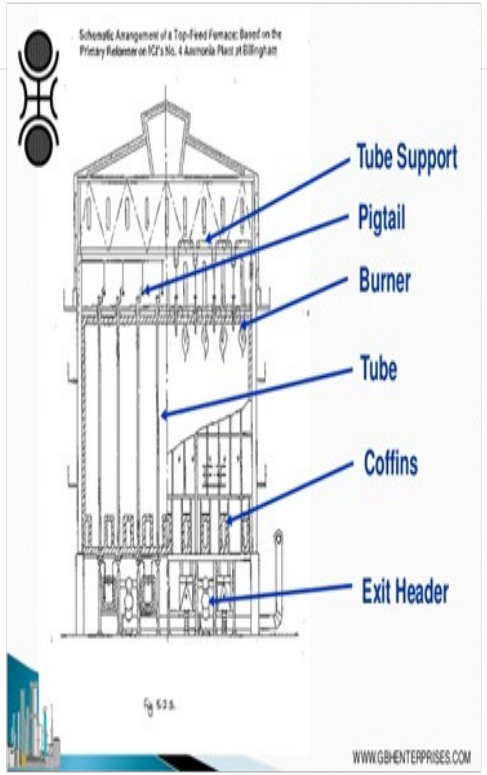
Cool GTL Products are High Quality



Cool GTL – Pilot Plant- Panoramic View

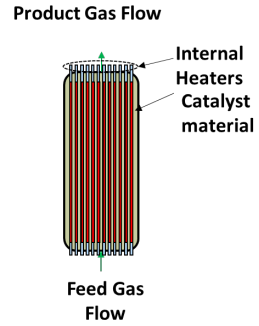
Electric Reformer Advantages

Typical Commercial Scale Stream Methane Reformer



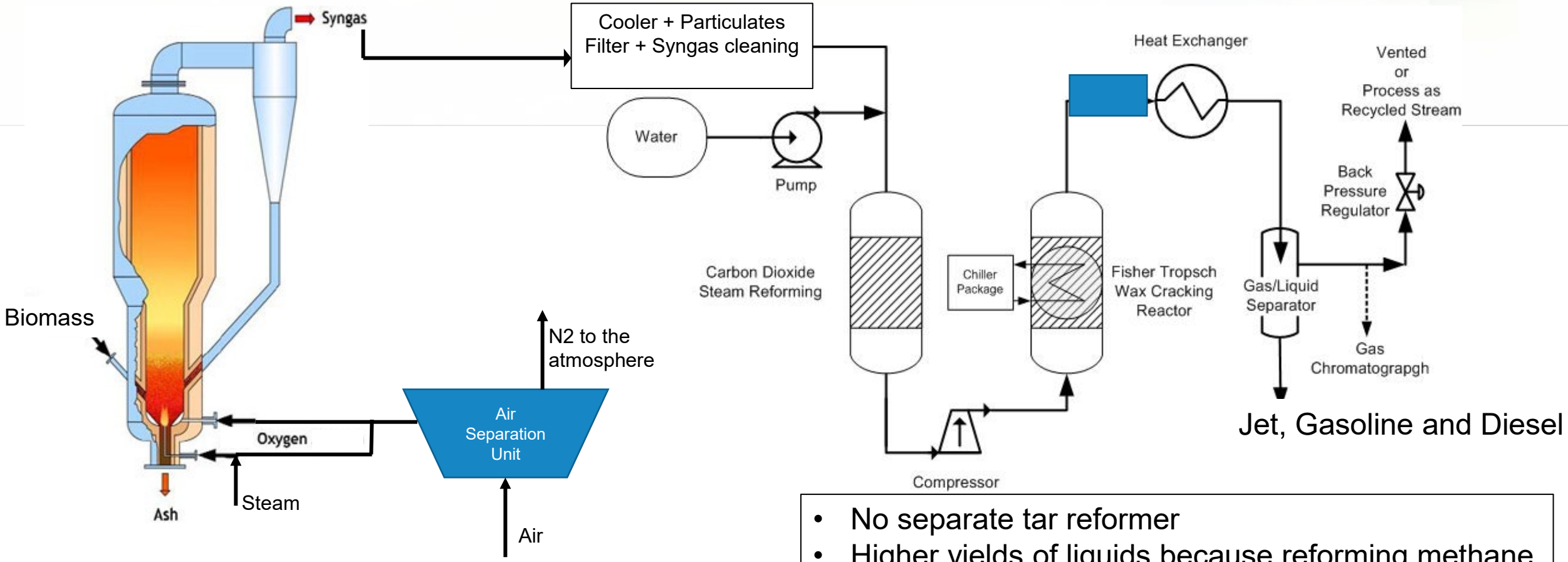
Moving from Gas fired reformer to electric reformer

GTI's Electric Reformer Design with Internal Heating Elements



Low Cost
Small Footprint
No CO2

Case Study 1: U-GAS + Cool GTL

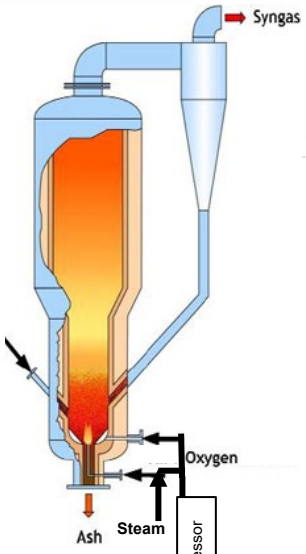


- No separate tar reformer
- Higher yields of liquids because reforming methane
- Directly makes synthesis gas with correct H2/CO
- No wax, directly makes jet diesel and gasoline

Case Study 2: U-GAS + Cool GTL + Electrolysis

Wind Power

Biomass

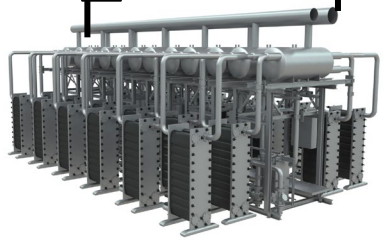


Cooler + Particulates Filter + Syngas Cleaning

Water

High-purity H2

Compressor



Electrolyzer

Carbon Dioxide Steam Reforming

Chiller Package

Fisher Tropsch Wax Cracking Reactor

Heat Exchanger

Vented or Process as Recycled Stream

Back Pressure Regulator

Gas/Liquid Separator

Gas Chromatograpgh

Liquid

Compressor

Jet, Gasoline and Diesel

A. Electrolysis capacity to provide the entire gasifier O2 needs
B. Electrolysis maximum capacity to reform all gasification CO2 products to biofuels

Performance of U-GAS + Cool GTL

- 1000 TPD Biomass U-GAS

	Case Study 1	Case Study 2	Case Study 2 – zero CO2
Liquid Yield GPT	57	90	159
CO2 product ton/ton biomass	.74	.47	0
H2 added ton/ton biomass	0	.036	.163
Power Usage (MWe)	13.9	103	315

Techno-economics of Case Study 1 & 2

- Biomass cost → $50/Ton, Over the fence power @ $50/MW-h
- 2025 Wind power CAPEX $1.034M/MW, Capacity Factor 0.467 (NREL ATB Data)
- 2030 Wind power CAPEX $0.7M/MW, Capacity Factor 0.498 (NREL ATB Data)
- Centralized PEM Electrolysis (> 100 MW) CAPEX: 2025 $1.3M/MW, 2030 $1M/MW.

	Case Study 1	Case Study 2	Case Study 2 – zero CO2
$ / Capital bbl - 2025	375,532	629,994	688,114
Levelized Cost of Gallon ($/Gal) –2025	2.51	2.82	2.83
$ / Capital bbl - 2030	375,532	532,249	541,644
Levelized Cost of Gallon ($/Gal) – 2030	2.51	2.53	2.41