Cool GTL
A New Biogas Conversion Process from GTI

Presented by Terry Marker, Senior Institute Engineer, Bioenergy Initiatives Manager, Gas Technology Institute

78 Year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY ▶ CONVERSION ▶ DELIVERY ▶ UTILIZATION

RESEARCH & DEVELOPMENT

PROGRAM MANAGEMENT

TECHNICAL/ ANALYTICAL

CONSULTING

TRAINING

COMMERCIALIZATION

360+ EMPLOYEES

World-class piloting facilities headquartered in Chicago area

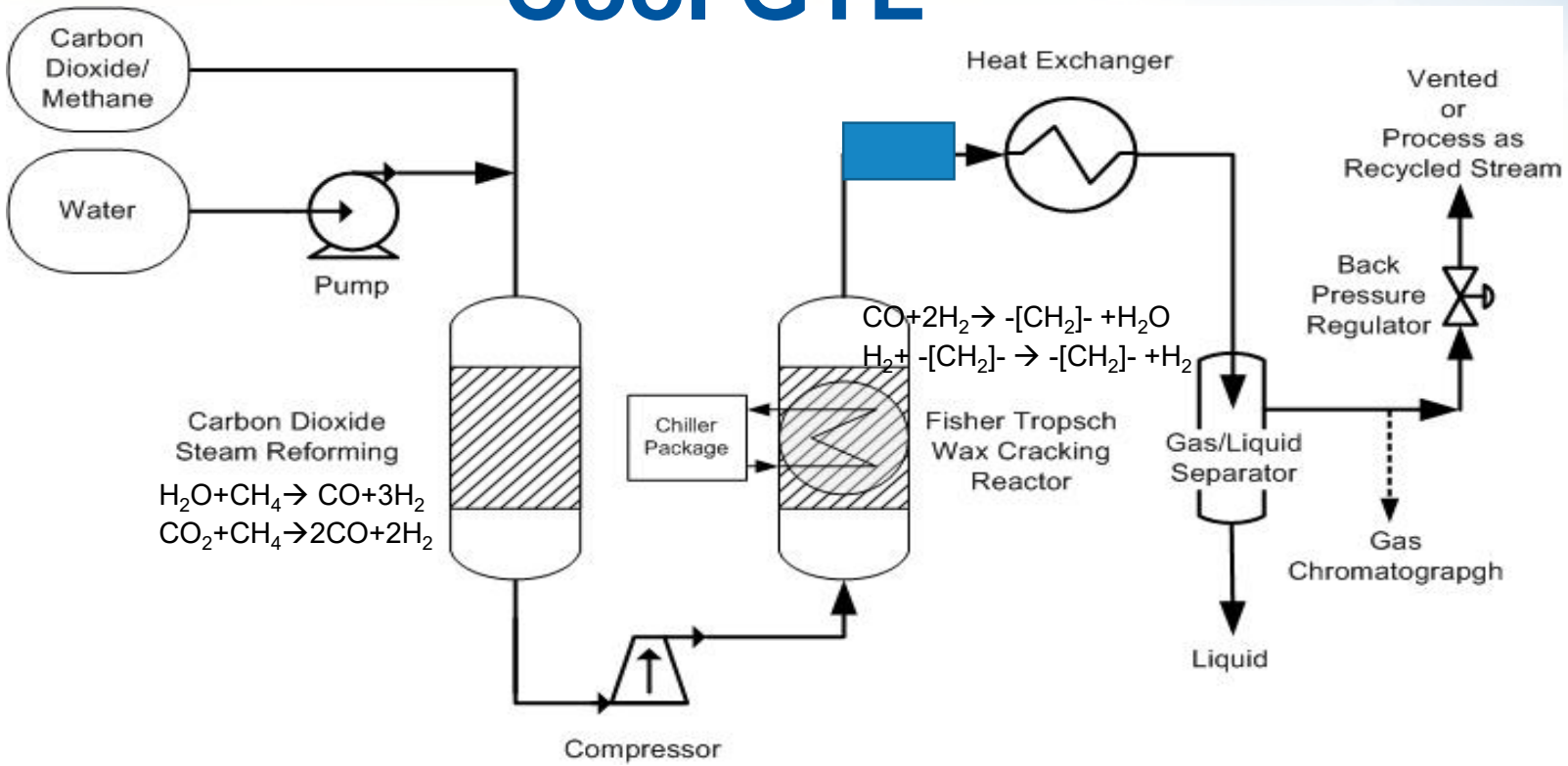
Cool GTL Goal

"It is always the simple that produces the marvelous." - Amelia Barr

- Simple modular design
- Utilize the CO_2 present in biogas as well as methane
- Low cost
- Skid mounted/Cookie Cutter
- Commercially Attractive
- How do you turn a complicated – expensive process into something commercially viable at small scale ? - **SIMPLIFY**

1. **"That's been one of my mantras - focus and simplicity. Simple can be harder than complex: You have to work hard to get your thinking clean to make it simple. But it's worth it in the end because once you get there, you can move mountains." - Steve Jobs**
2. **"Truth is ever to be found in simplicity, and not in the multiplicity and confusion of things." - Isaac Newton**

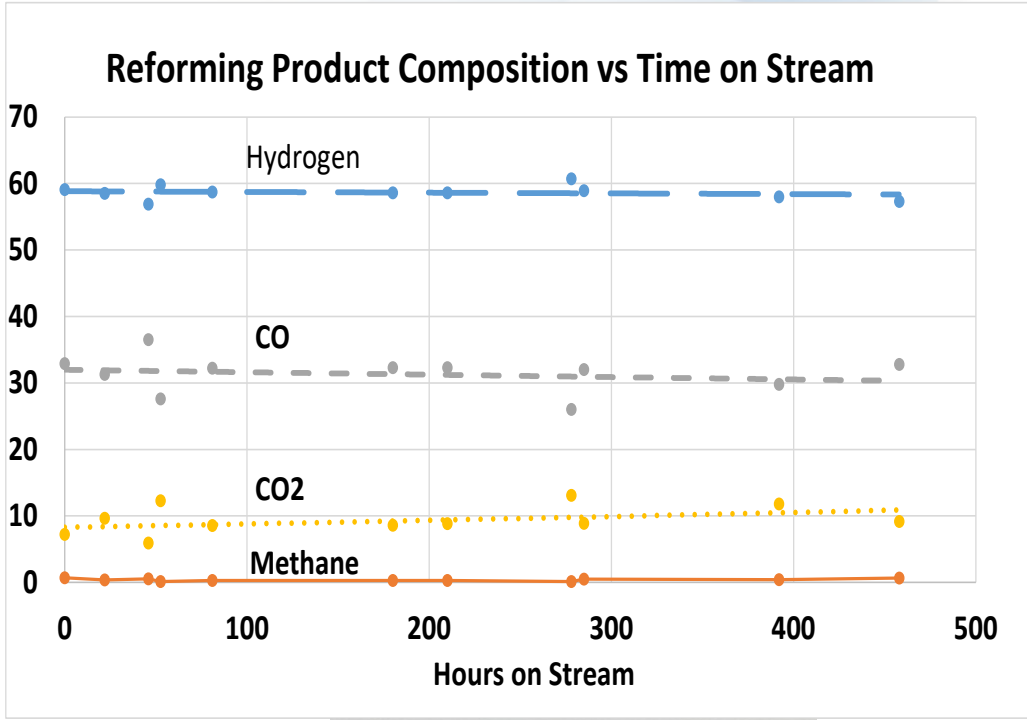
Cool GTL



- 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 -2.4:1 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



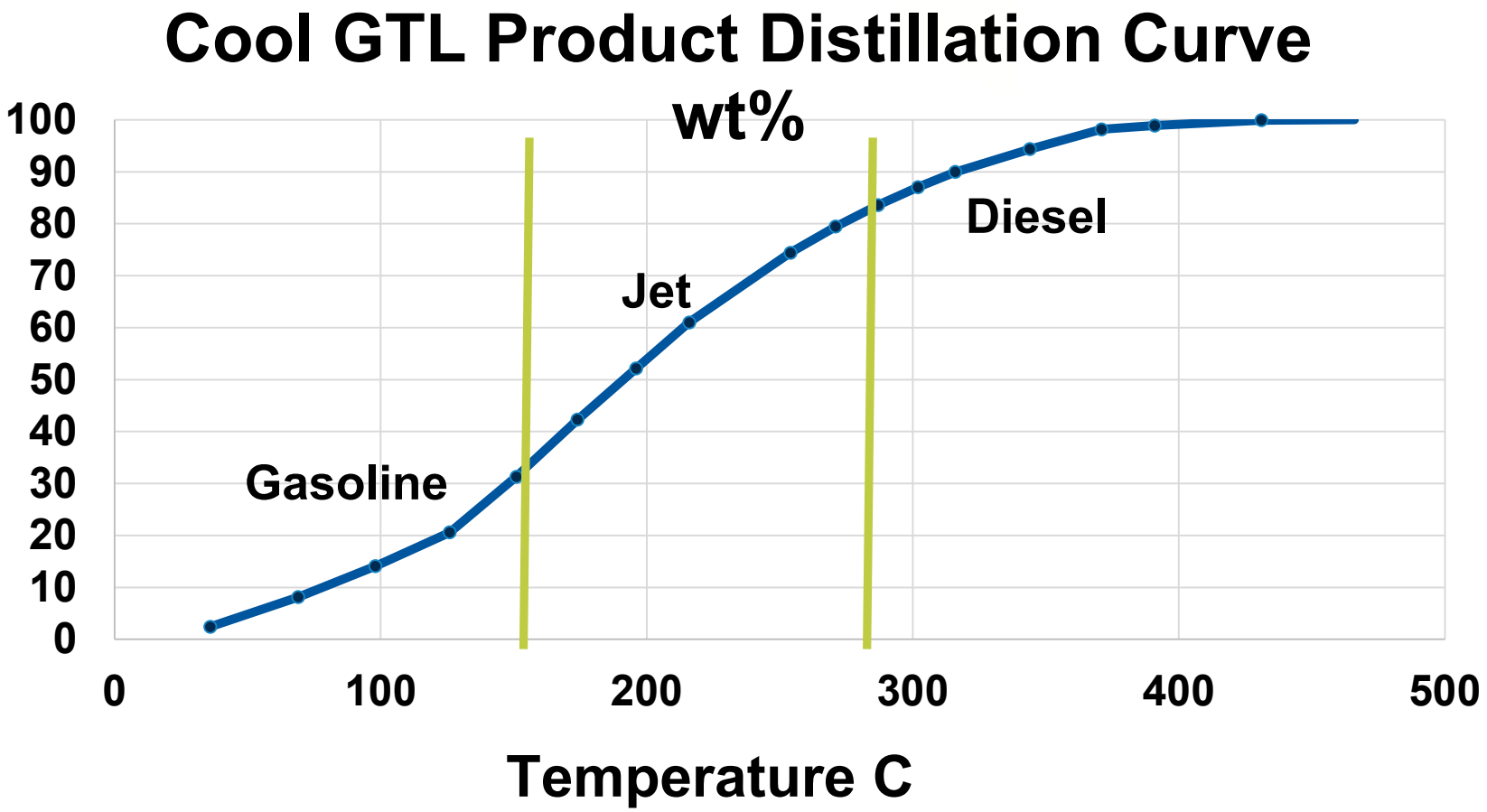
Clean Hydrocarbon Product

Low cost, simplified version of a traditional process.

Why Combine Fischer Tropsch with Wax Cracking/Isomerization ?

- NO wax !
- High per pass conversion
- Simplified product slate
- Low cost reactor
- Easy scale up and scale down
- Follow on polishing wax cracking/isomerization reactor to insure complete wax conversion

Cool GTL Products are High Quality



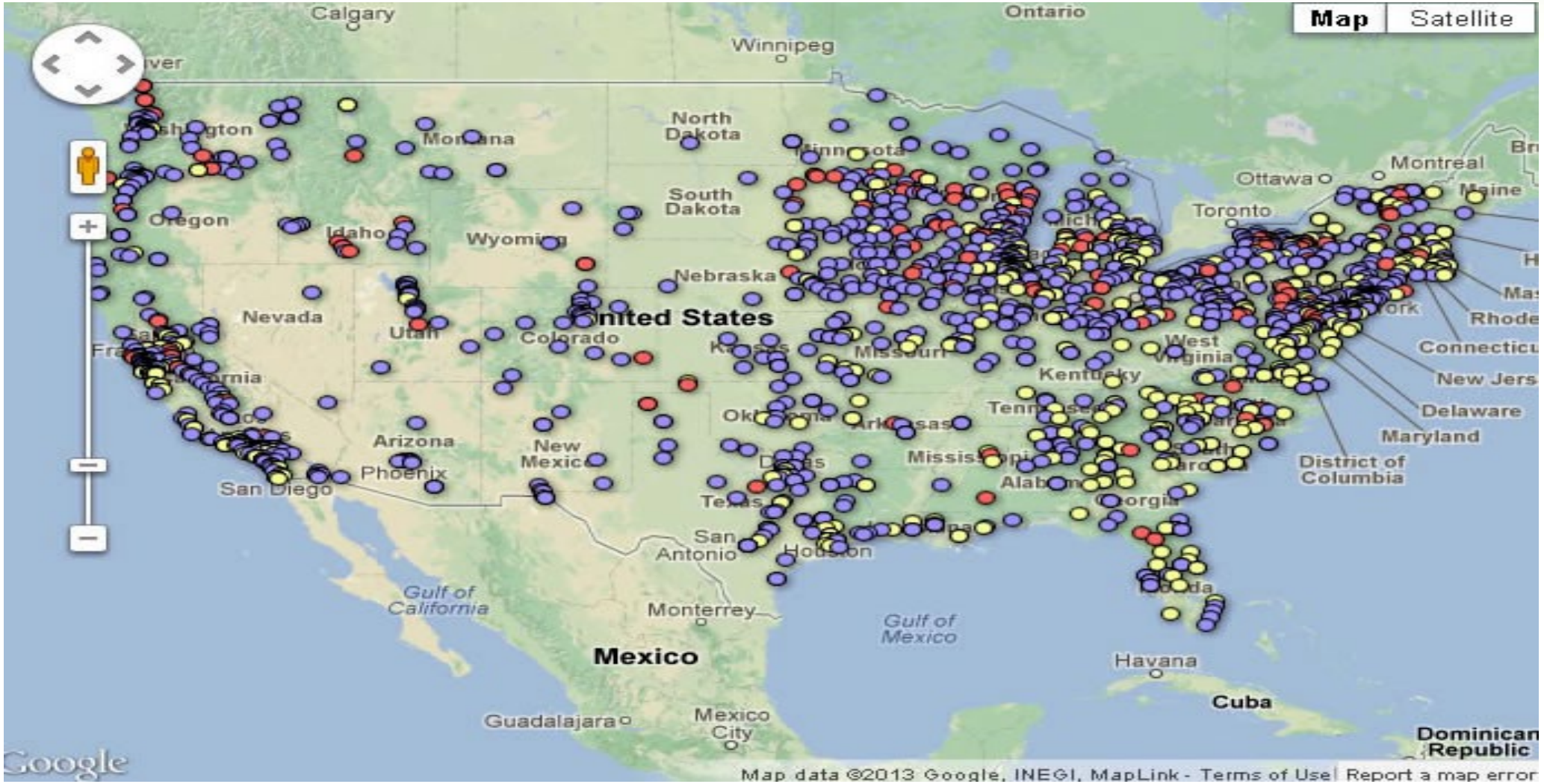
Freeze Point = -2C

Laboratory Scale Cool GTL – Reformer and Fischer Tropsch

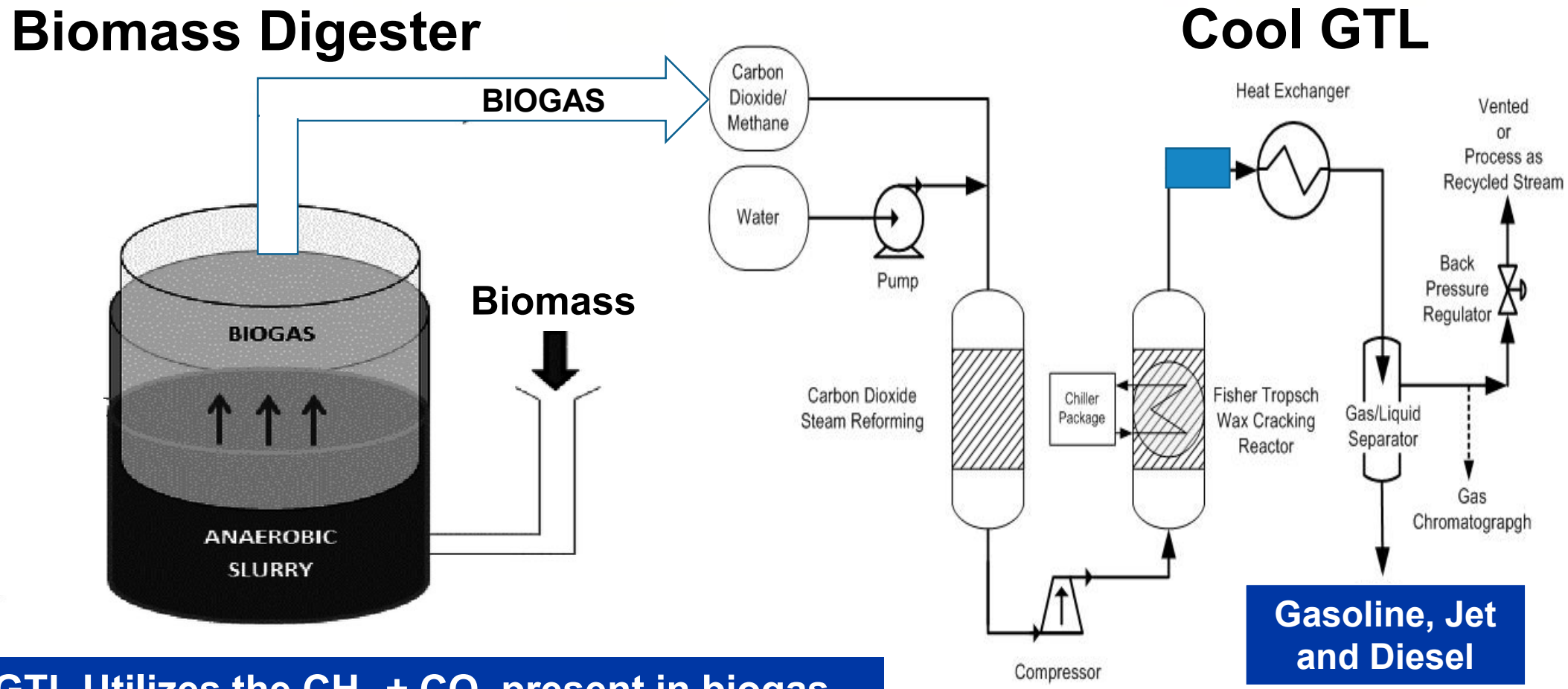
Cool GTL Reactions

(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

Many Biogas Locations in United States



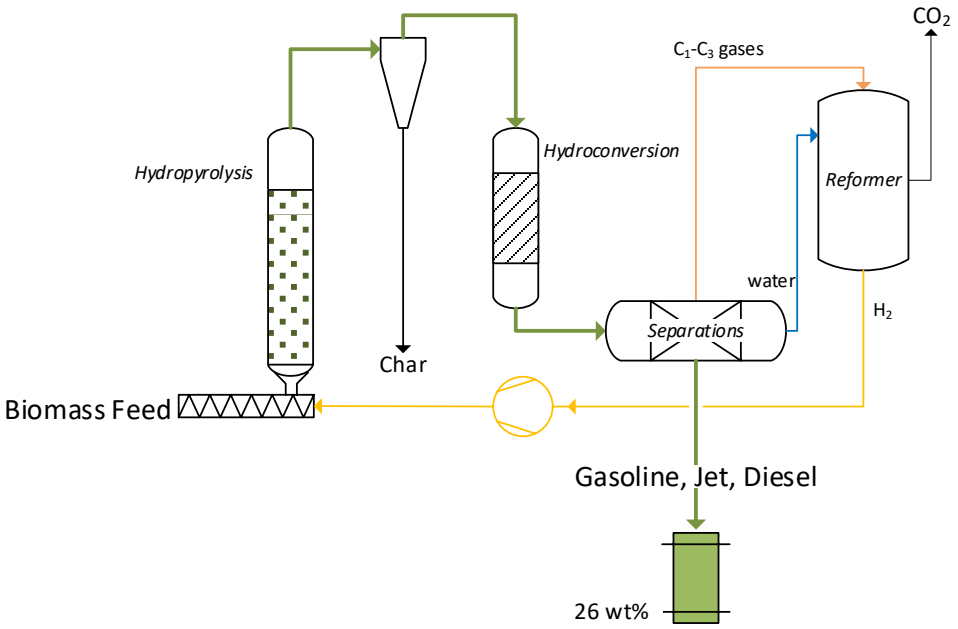
Cool GTL for Biogas Conversion



Cool GTL Utilizes the CH_4 + CO_2 present in biogas

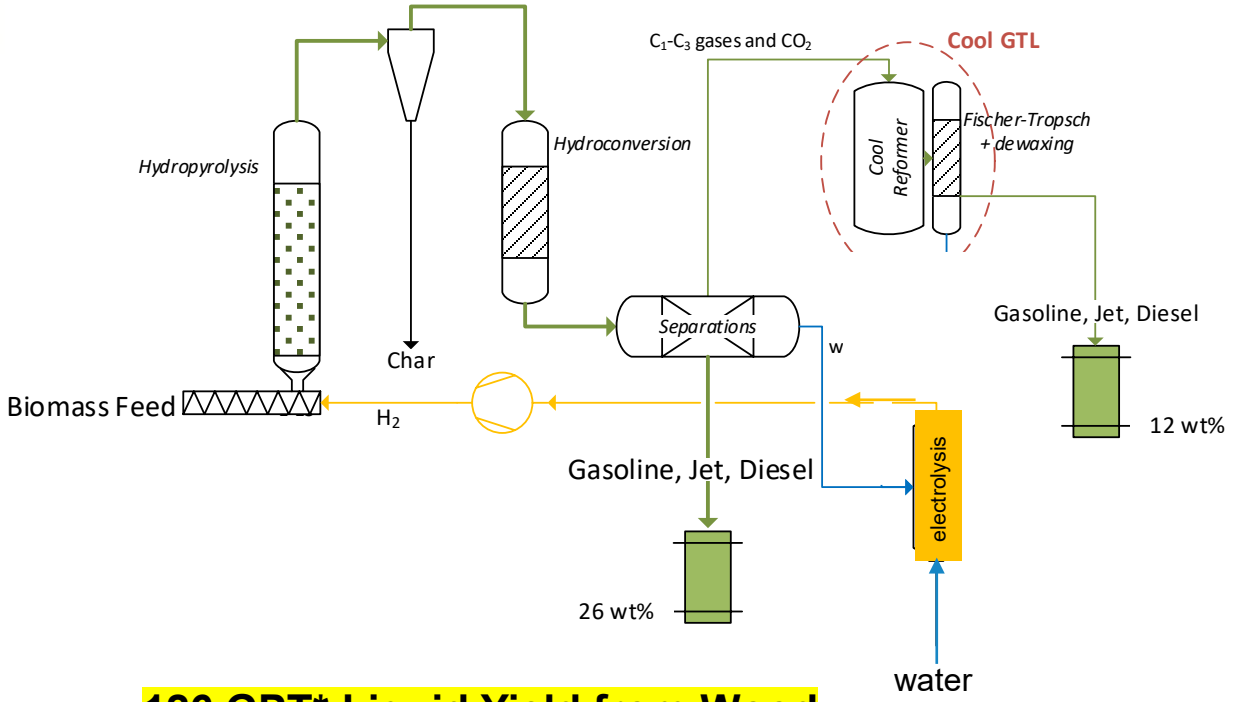
Integrated Cool GTL - IH²® Case

IH² Process



86 GPT* Liquid Yield from Wood

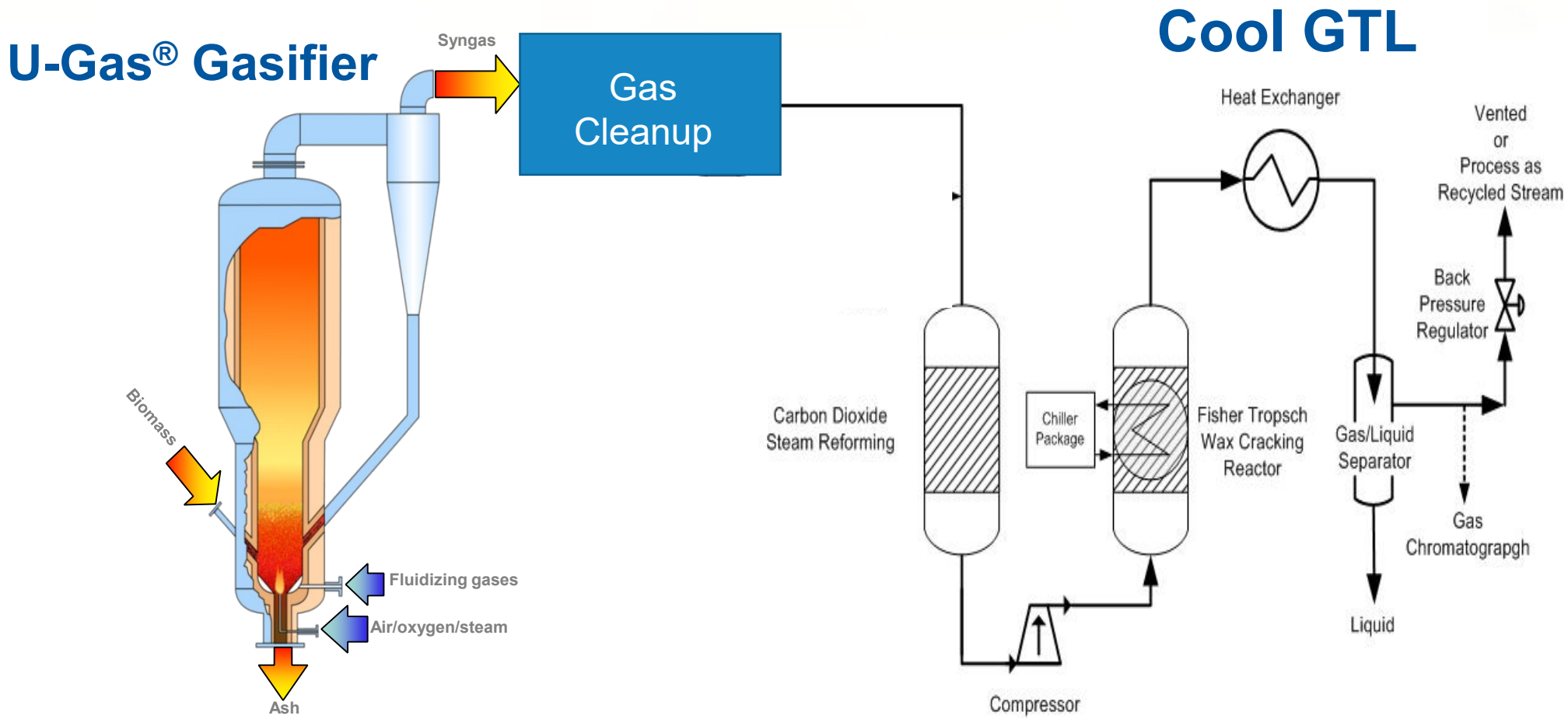
IH² Process with Integrated Cool GTL



126 GPT* Liquid Yield from Wood

- Use electrolysis to make H_2 from water use biogenic gas to make more biogenic liquids.
- LCA shows IH² + Cool GTL liquids still provide >60% GHG reduction.

U-Gas Gasifier + Cool GTL



Best Integration under Review

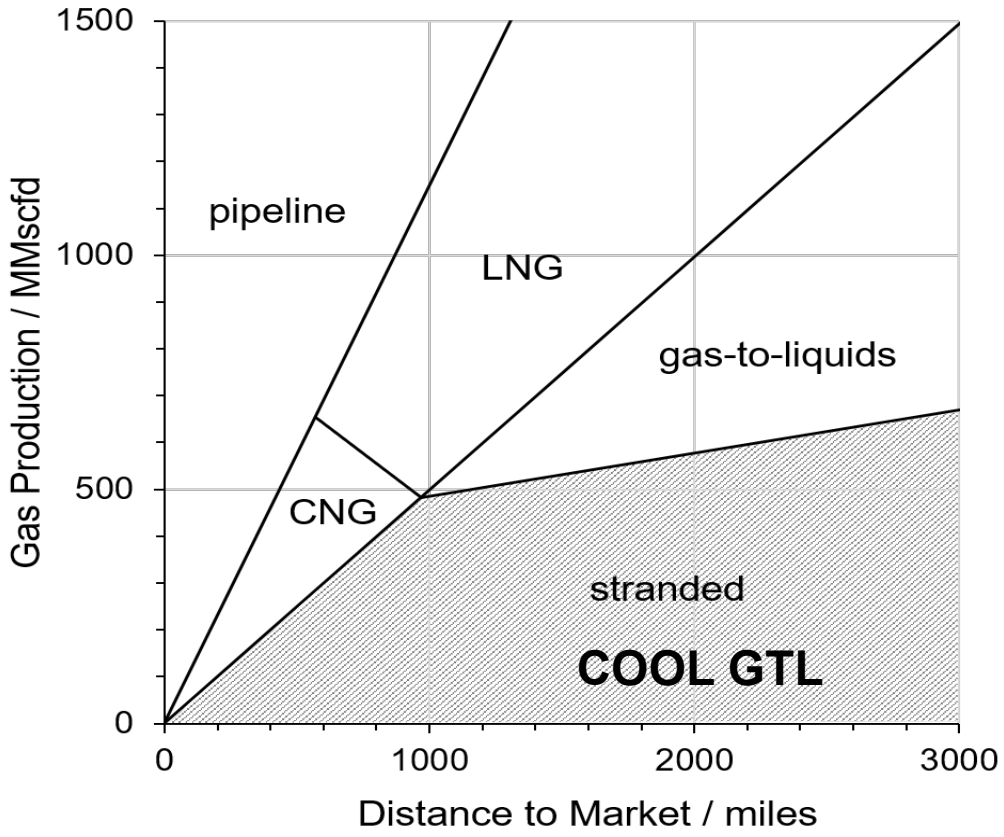
Cool GTL Applications & Markets

- Biogas to GTL → Direct utilization of CO_2 methane, ethane, propane
- Integration with Gasifier – wood to drop in gasoline jet and diesel
- High CO_2 content natural gas → utilize some shut-in natural gas
- Flare gas mitigation → any CO_2 containing natural gas, offshore, Africa

Cool GTL was Designed from the Beginning for Modular Deployment

Applications typically small in size (such as biogas plants, associated gas, and individual oil wells), and locations with limited takeaway infrastructure call for:

- Simplified process
- Compact equipment
- Small footprint



Relative U.S. Fuel Prices

	$/bbl oil equivalent
Biogas	15
Natural Gas	20
Crude	70
Jet/Gasoline/Diesel	80
Product Value Incentive	**65**

Liquid fuels are easy to transport and valuable.

Cool GTL Preliminary Economics *

	Cool GTL for IH² Application	Cool GTL for Digester Biogas
Liquid product made (bbl/d)	434	200
Value of product ($/gal)	$2.50 (as refined biogenic liquid)	$2.50
Product value/year ($)	15,960,000	$6,930,000
Value of feed gas ($/MMBtu)	$3.00	$3.00
Overall incentive ($ million/year)	12.9	5.94
Modular capital estimate ($ million)	29.9	18.6
Additional OSBL* costs ($ million)	6.0	2.7
Estimated erected costs ($ million)	35.4	21.3
Years to simple payback (years)	2.7	3.1

* Base on modeling and lab tests

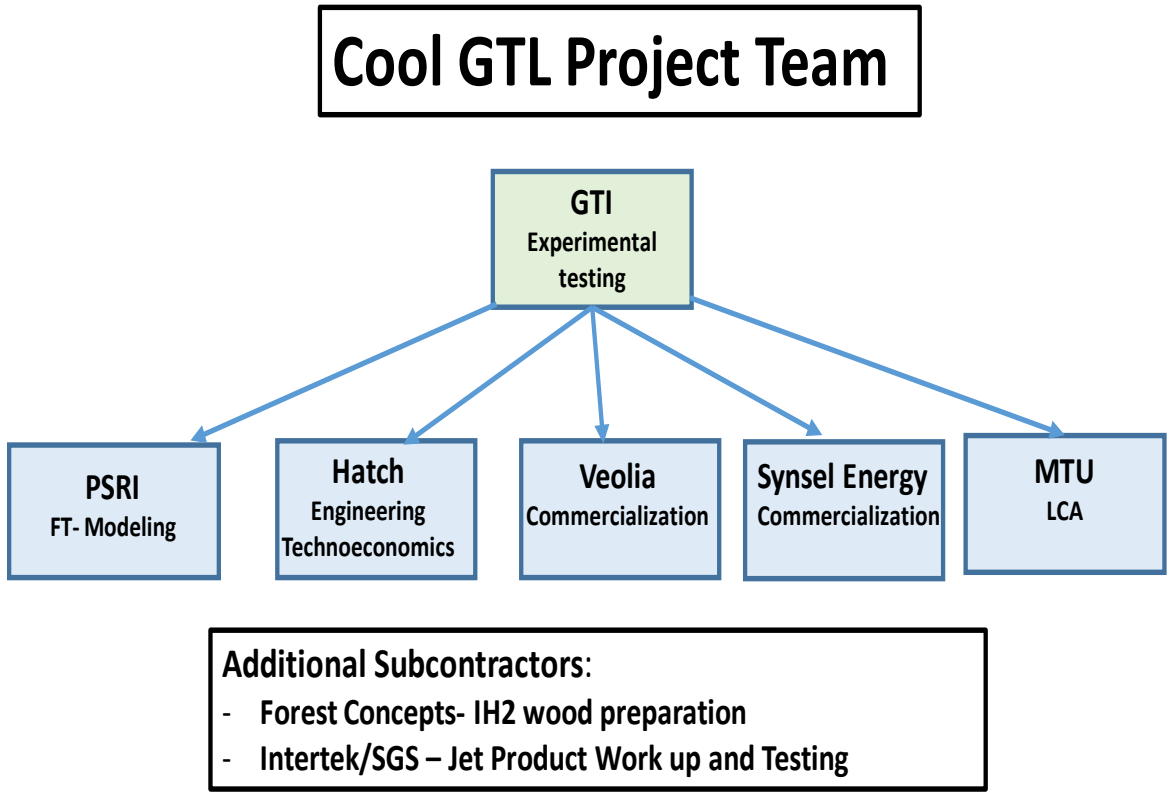
*OSBL = outside battery limits

Cool GTL Status

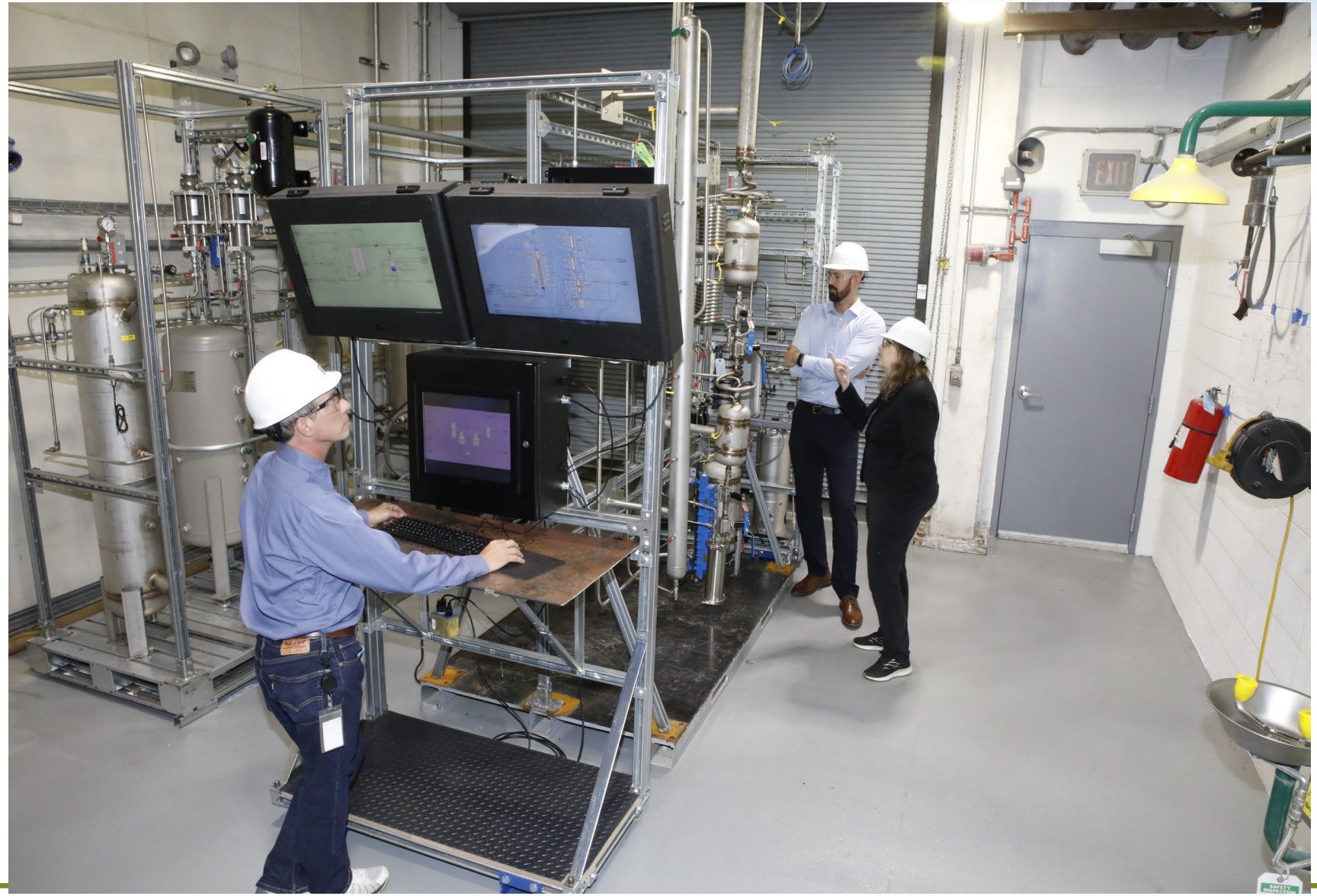
- Three patent applications filed
- Requires longer-term tests
  - Validate catalyst life
- Requires larger-scale, skid-mounted modular testing
  - Validate at larger scale
- Three years from commercialization
- Requires a commercialization partner
- New DOE Project Biogas to Jet Fuel kicked off Sept 2019

New DOE Cool GTL Project Kicks off

- Scale up the Cool GTL and demonstrate at a larger scale
- Make 100 gallons of high quality jet fuel from biogas
- Use a real biogas feed for Cool GTL feed
- Show high conversion per pass for FT
- Show Cool GTL Process and Stability
- Fully integrated and fully automated- round the clock operation



Larger Scale Cool GTL Pilot Plant



GTI-Turning Ideas into Practical Solutions

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