Cool LPG: A new path to renewable LPG

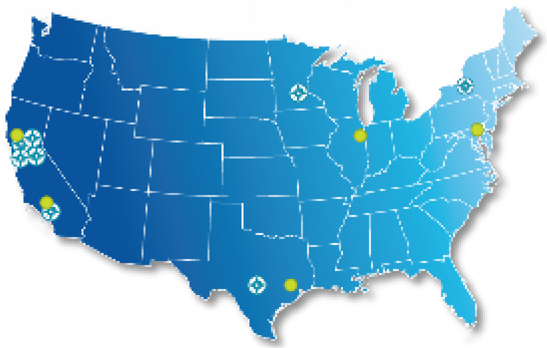
April 2022

Dr. Patrick Littlewood, Principal Scientist
Terry Marker, Senior Institute Engineer
Dr. Pedro Ortiz-Toral, Bioenergy Program Manager
Dr. Markus Lesemann, Director, Business Development

80-year History of Turning Raw Technology into Practical Energy Solutions

FOR A BETTER ECONOMY AND A BETTER ENVIRONMENT

SUPPLY	CONVERSION	DELIVERY	UTILIZATION
			



World-class piloting facilities headquartered in Chicago area

- RESEARCH & DEVELOPMENT
- PROGRAM MANAGEMENT
- TECHNICAL/ ANALYTICAL
- CONSULTING
- TRAINING
- COMMERCIALIZATION

400+ EMPLOYEES

gti®

The upcoming need for bioLPG in the U.S.

- Nearly 2% of the U.S. energy needs are supplied LPG. In 2015, about 1 million barrels were consumed per day.
- As of 2017, nearly 830,000 farms in the U.S. use LPG.
- About 7 million households nationally and roughly 8% of the homes in the Midwest are heated with LPG. For example, in 2012 Wisconsin used 245 million gallons of LPG, over 87% of which was used for residential purposes.
- LPG is of special value to disadvantaged rural and Native American communities which are often dependent on LPG for heating and cooking.

LPG is a fossil byproduct. As less fossil resources are utilized, there is no substitute for the byproduct LPG.

The upcoming need for bioLPG in the developing world

- Modern energy cooking services (MECS), the ability to cook efficiently, cleanly, conveniently, reliably, safely and affordably, are now regarded as an urgent human development priority.
- Globally, 4 billion people lack MECS.
- Nearly 1 bn people in Sub-Saharan Africa cook with traditional solid fuels (wood, charcoal, manure), and a growing number of deaths (est. ~ 0.5 million per year, 2021) are directly attributable to smoke and pollution from such cooking fuels.
- LPG is an economically efficient, cooking energy solution already used by over 2.5 billion people worldwide.
- … but LPG is an imported fossil fuel in SSA (and in many parts of the developing world), and it is increasingly difficult for fossil projects to receive development funding for fossil fuel infrastructure.

BioLPG is chemically identical to fossil LPG and can help provide MECS while meeting international climate targets

1) GLPGP. Assessing Potential for BioLPG Production and Use within the Cooking Energy Sector in Africa. Available online: glpgp.org/resources (accessed 4/14/2022).
2) Chen, K.C.; Leach, M.; Black, M.J.; Tesfamichael, M.; Kemausuor, F.; Littlewood, P.; Marker, T.; Mwabonje, O.; Mulugetta, Y.; Murphy, R.J.; et al. *Energies* **2021**, 14, 3916.

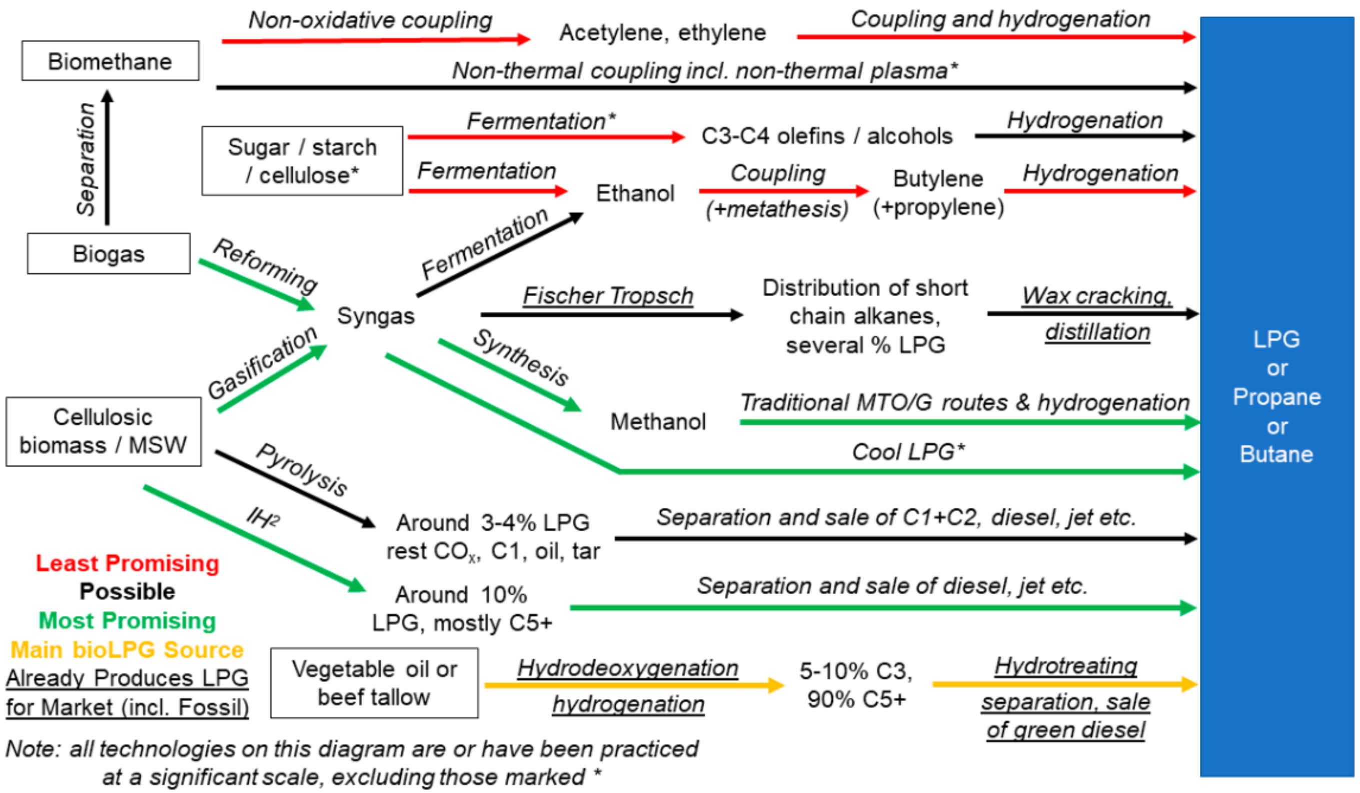
Lack of viable bioLPG production routes

There are no existing commercial routes that produce renewable or bioLPG as a primary product. Only HVO routes (using feeds like vegetable oils) produce significant quantities of LPG as minor green diesel byproduct.

GTI, Global LPG Partnership (GLPGP) and University of Surrey study indicated lack of viable options for routes to bioLPG.

Chen, K. C. *et. al* *Energies* **2021**, 14, 3916.

https://doi.org/10.3390/en14133916

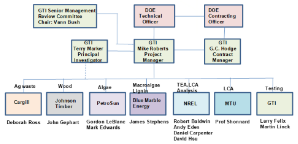


There is no developed process targeting bioLPG

Commercialization example: IH²® biomass to fuels technology with Shell

Early development in partnership with US DOE Bioenergy Technologies Office (BETO)

IH² Project Team



- U.S. DOE Award DE-EE-0002873
- SOW: Mini-bench tests, initial continuous testing, TEA update, LCA update
- Apr 2010 – Dec 2012

- Parallel project funded by CRI/Shell
- SOW: Design and build IH²-50 pilot plant
- Delivered to GTI on Sept 2011

IH² TECHNOLOGY

Extract value from non-food organic waste such as forestry, agricultural residues, aquatic plants and (ligno)cellulosic fractions of municipal waste by turning them into transportation fuels using a continuous catalytic thermochemical process.

Integrated Hydropyrolysis and Hydroconversion

Convert a wide range of organic wastes to liquid hydrocarbon transportation fuels efficiently.

Strategic Alliances for Waste to Fuel Technology

Shell Catalysts & Technologies partners with a number of companies in the upstream & renewables market with IH² technology.

Catalysts for IH² Advanced Biofuels Technology

Improve the IH² process with advanced biofuel catalysts. Shell Catalysts & Technologies develops catalyst formulations that fulfil IH² technology process requirements.

Biomass to Fuels: IH² Commercial Process Optimisation

More than 30 process and catalyst patents have resulted from efforts at Shell Technology Centre Bangalore in collaboration with GTI.

IH² Demonstration Facility

Operating at 5 metric tonnes per day, this facility converts forestry, agricultural and urban waste into fungible hydrocarbon transportation fuels.

Contact Shell Catalysts & Technologies

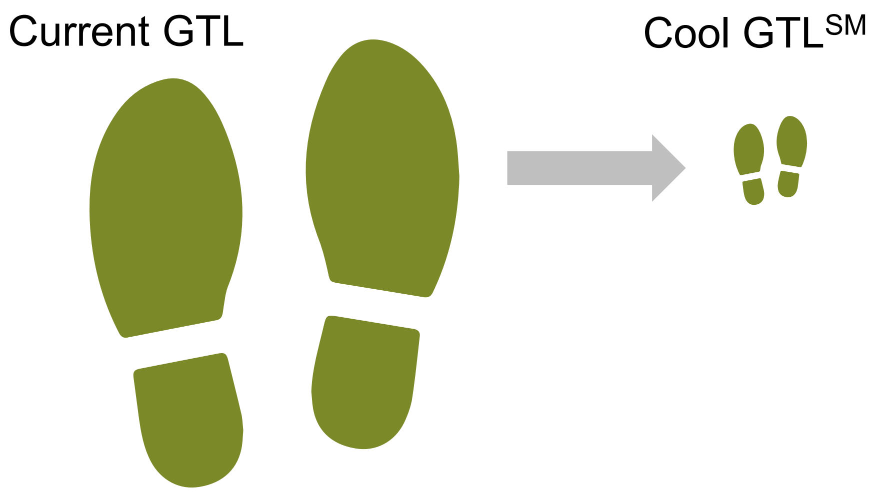
Contact Shell Catalysts & Technologies to meet the challenges petrochemical plants face with confidence.

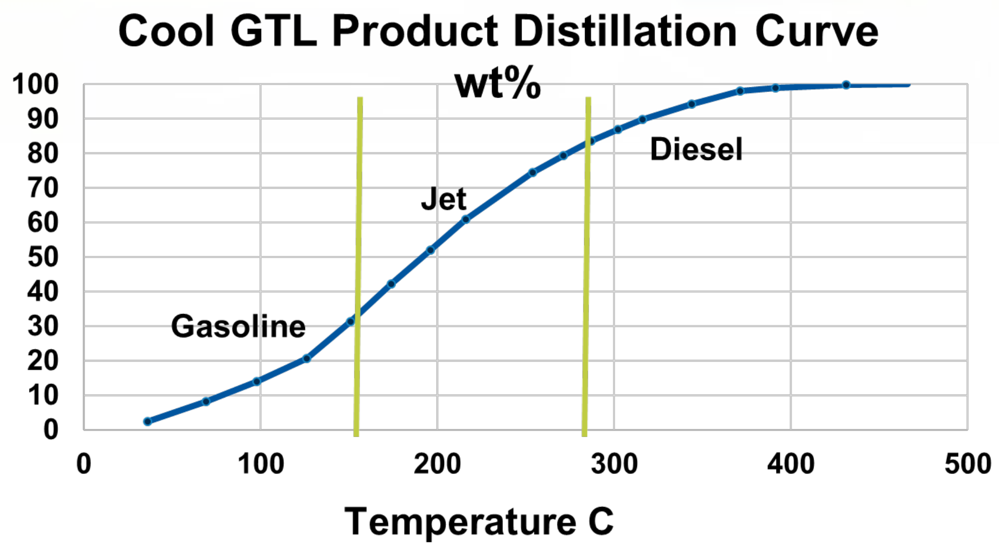
Source: IH² Technology | Shell Catalysts & Technologies | Shell Global

Cool GTL℠ Unique sustainable liquid fuels platform at GTI

Beneficial Results

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





Cool GTL℠ can produce sustainable liquid fuels

(but does not solve the need for bioLPG)

Cool GTL℠ – Platform can be expanded to LPG

Cool GTL℠

Cool LPG℠

Expansion to LPG production

Route to directly produce LPG from biogas with substantially lowered GHG emissions.

Cool LPG℠

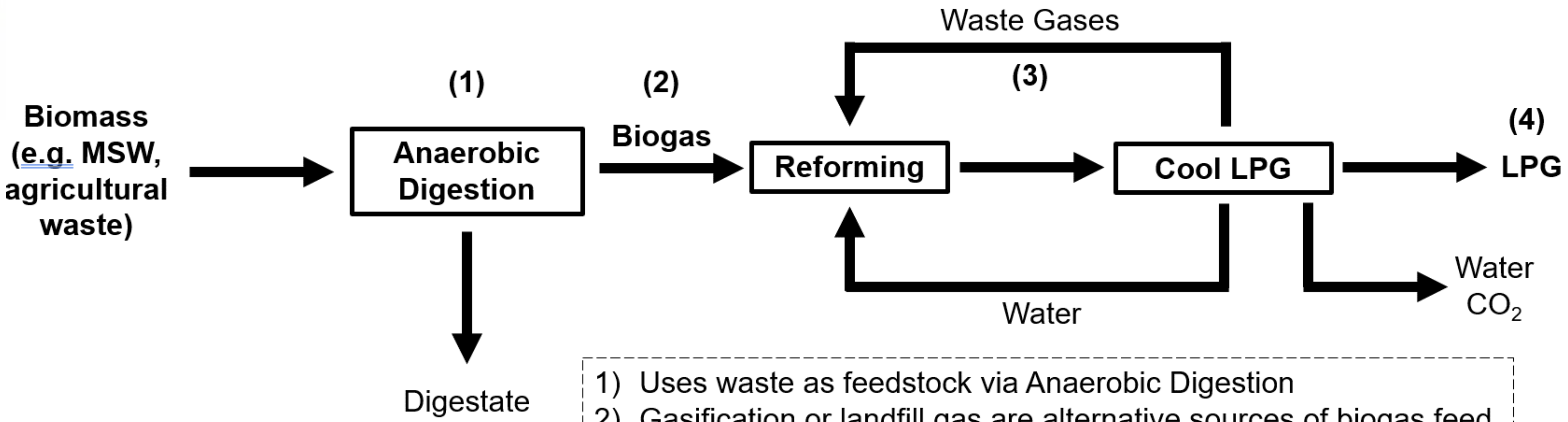
Features

- Self-contained, able to run entirely on biogas
  - Converts "commodity fuel" bio-derived methane to "premium fuel" bio-derived LPG
  - Converts bio-derived CO_2 to bio-derived LPG
- Expected to be highly scalable based on industrial experience in reforming, methanol synthesis and conversion processes
- Can leverage renewable electricity (E-Reformer)

SELECTIVE FOR LPG (unlike Fischer-Tropsch, HVO route etc.)

Initial development work has commercial backing (BioLPG, LLC)

Cool LPG℠ Process Diagram



1) Uses waste as feedstock via Anaerobic Digestion
2) Gasification or landfill gas are alternative sources of biogas feed
3) Heat and byproducts from Cool LPG are recycled
4) LPG is the primary product

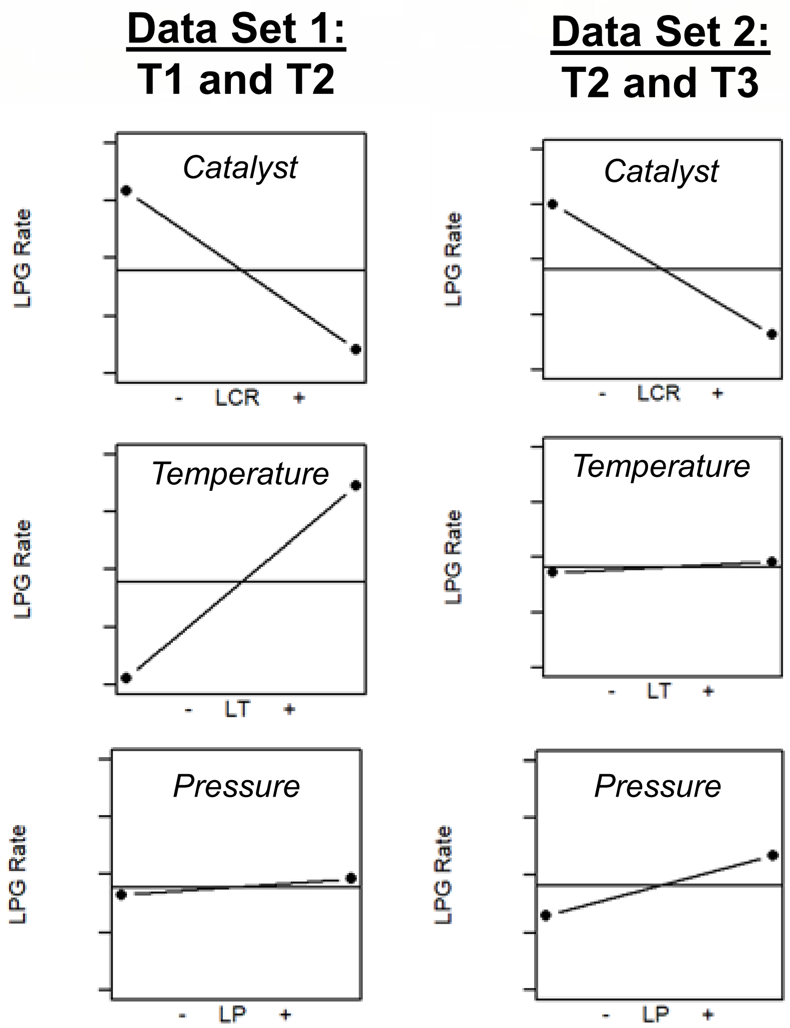
- Converts biogas CO_2-CH4 to LPG containing propane and butane
- Uses unique CO_2/steam reforming catalyst to directly make 2:1 H_2/CO synthesis gas
- Uses unique combined 2[nd] stage which makes methanol and then LPG in 2nd stage
- Simple and compact with unique catalysts in each stage

Cool LPG℠ Reactions

(I) $H_2O+CH_4 \rightleftharpoons CO+3H_2$	CO and H_2 formation (800°C)	Reactor 1
(II) $CO_2+CH_4 \rightleftharpoons 2CO+2H_2$	CO and H_2 formation (800°C)	Reactor 1
(III) $CO_2+H_2 \rightleftharpoons H_2O+CO$	Water-gas shift to equilibrium	Reactor 1

(IV) $CO+2H_2 \rightleftharpoons CH_3OH$	Methanol Formation	Reactor 2
(V) $7CH_3OH+2H_2 \rightarrow C_3H_8+C_4H_{10}+7H_2O$	LPG Formation	Reactor 2

Cool LPG℠ Effects of Reaction Conditions



Example data: statistical experimental design.

Data are shown for two catalysts (C1, C2).
Three temperatures (T1, T2, T3) are shown.
Two pressures are shown (P2 is approximately double P1).

The y-axis shows the normalized effect on the LPG production rate.

Catalyst choice by far the most important factor!

Existing Test Facilities

- Catalyst testing capabilities at GTI from the milligram scale upwards.
- "Mini-scale" to "bench-scale" to pilot scale all possible with GTI's existing facilities.
- Allows rapid development of catalyst and process.

Mini Scale	Bench Scale
	
Milliliters per minute flow	Liters per minute flow
Milligrams or grams powder catalyst	Tens or hundreds g's granular or pellet catalyst
Reactor diameter around ½"	Reactor diameter minimum ½"
High precision mass flow controllers	High precision mass flow controllers
Dedicated online GC (Gas Chromatograph)	Dedicated online GC
Control and data acquisition by PC	Control and data acquisition by PC
Catalyst changeover time 1 hour	Catalyst changeover time 1 day

Existing Test Facilities

Existing pilot facilities can be leveraged for low cost, fast paced development

Cool LPG[SM]

Preliminary Results Promising

- Initial catalyst development completed & process operating space explored
- High selectivity to LPG
- Process model built demonstrating >65% LPG yield from incoming biomethane based on performance measured in the lab
- All light ends can be recycled to extinction back to first stage reformer

Rapid scale-up possible using existing Cool platform at GTI

Licensing agreements with GLPGP and BioLPG, LLC

- The Global LPG Partnership (GLPGP) is a UN-backed not-for-profit organization, formed in 2012 under the UN Sustainable Energy for All initiative, committed to helping transition large populations to LPG for clean, modern cooking. The GLPGP vision is to help transition one billion people to the adoption and use of LPG for cooking by 2030
- BioLPG LLC is focused on providing the decarbonization potential of bioLPG to commercial, industrial, and household LPG users in more developed countries, to help LPG industry stakeholders meet their and their governments' ambitious net zero carbon emissions goals

"We are eager to facilitate and scale up a transition to green LPG in both developing and developed countries. Building Cool LPG facilities can create the viable transition for many hundreds of millions of people to renewable LPG within the next decade,"

– *Kimball Chen, Chairman of GLPGP and CEO of BioLPG LLC*

THE GLOBAL LPG PARTNERSHIP

gti

THE GLOBAL LPG PARTNERSHIP

BioLPG, LLC

Thank you for listening!

Terry Marker
Sr Institute Engineer

Dr Pedro Ortiz-Toral
Bioenergy Program Manager

Megan Huang Herrera
Sr Engineer

Dr Markus Lesemann
Director, Business Development

John Whitehouse
Sr Tech. Comm. Mgr