On-Purpose Bio-LPG from multiple feedstocks

Dr Keith Simons, Chief Technology Officer

September 2024

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SHV ENERGY

4 continents

26 million customers

24 countries

12,956 employees

Our brands

CALOR
GASPOL
iPRAGAZ
LIQUIGAS
PETROMAX LPG
PINNACLE
PRIMAGAZ
PRIMAGAS
PRIMAGAS
SUPERGAS
SUPERGASBRAS
BUTAN PLIN
PRIMA LNG
SHV ENERGY SUPPLY & RISK MANAGEMENT
FUTURIA FUELS
EM3 An SHV Energy Company
SunSource ENERGY An SHV Energy Company

Our Energy Solutions

Our domestic, leisure, commercial, industrial and transportation customers benefit from using our cleaner energy sources.

Heating

LPG is used in off-grid homes with boilers and heating appliances, in offices and by farmers for heating greenhouses.

Transport

LPG is the world's most popular alternative automotive fuel. It's used in over 25 million vehicles around the globe.

Cooking

LPG provides a cleaner energy source for cooking than coal or heating oil, and it can be connected to any home cooking appliance.

Commercial

LPG is used by commercial customers to reduce their use of higher-carbon, polluting energy sources. In developing countries, LPG replaces hazardous solid fuel used for cooking stoves.

Industry

LPG is used for a wide range of industrial applications and processes, such as heating, cooling, drying, processing and food production.

Domestic

LPG provides energy for the home, as well as for a range of leisure activities from BBQ grills to caravanning and mobile catering.

Guidelines for LPG specification* vary worldwide

Country	Reported propane/butane mixture
Austria	from 100:0 to 80/20
Belgium	60:40 all year
Czech Republic	60:40 in winter 40:60 in summer
Denmark	70:30 from 1/09 to 31/05
Finland	95:5 from 1/09 to 31/05
France	100:0 to 60:40 from 1/11 to 31/03, 40:60 to 30:70 in summer
Germany	60:40 to 40:60 from 01/12 to 31/03, 10:90 to 0:100 in summer
Greece	20:80 all year
Hungary	40:60 all year
Ireland	100:0 all year
Brazil	Typically ranging from 30:70 to 50:50; contains variable amounts of propane, propylene, butane, butylene, and/or other
USA	HD-5: Minimum 90% propane, maximum 5% propylene and other HD-10: Minimum 90% propane, maximum 10% propylene and other Commercial propane: Minimum 80% propane, maximum 20% propylene and other

Source: includes European LPG Association, myLPG.eu; *N.B., these specifications are for autogas

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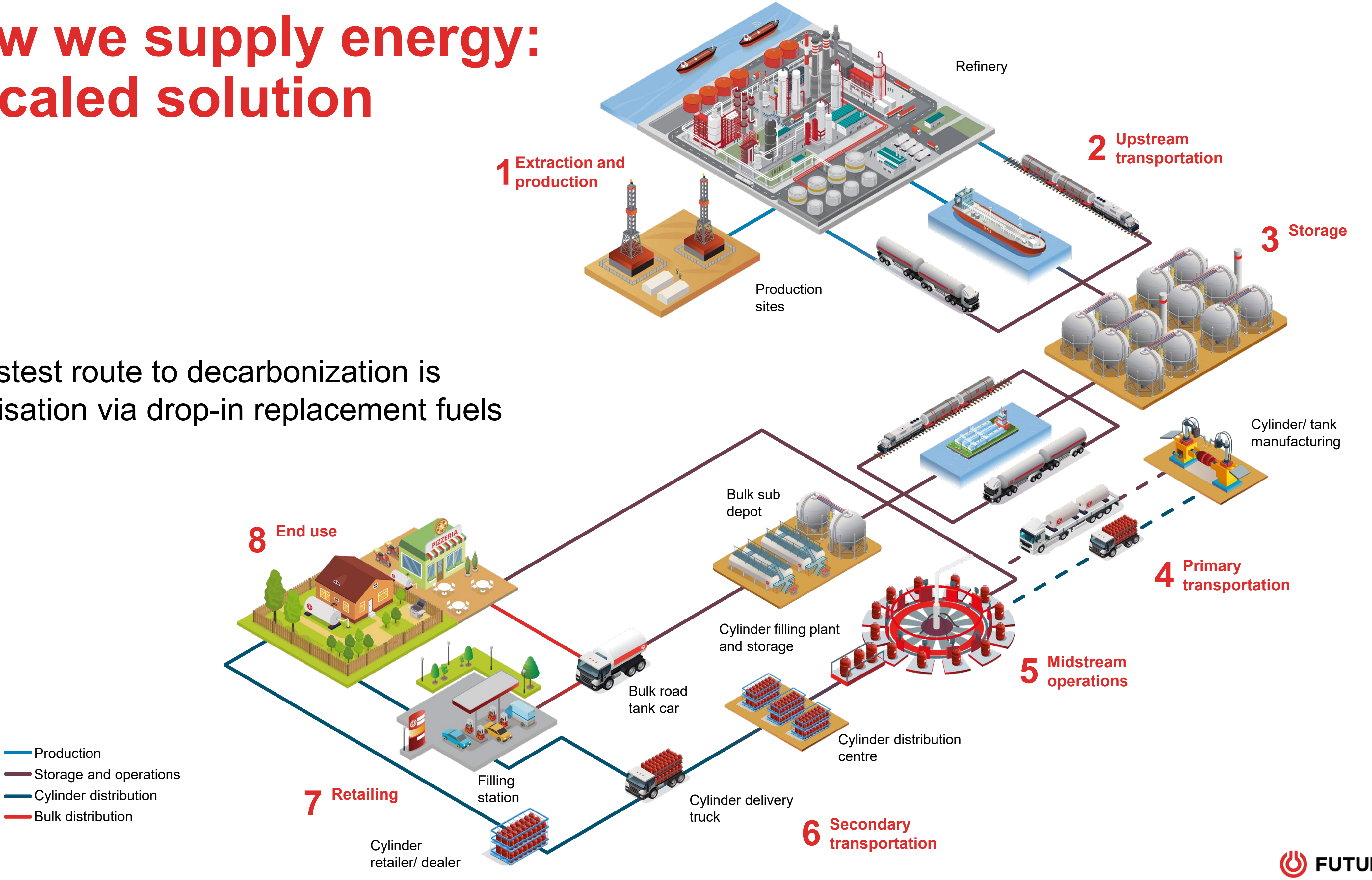
The global LPG market is a massive opportunity

- **At 342 million MT/a, the global LPG market is comparable to aviation fuel**
- Fossil propane / butane traditionally a by-product from gas processing / crude refining
- WLGA membership targeting up to 50% substitution of the 2050 global non-chemical LPG demand
- BioLPG is currently a by-product (around 5% yield) from the HVO / HEFA process to produce bio-Diesel / SAF
- BioLPG often reformed to hydrogen to reduce the carbon intensity of Biodiesel / SAF

Image source: WLPGA Annual Report 2023

How we supply energy: a scaled solution

The fastest route to decarbonization is defosilisation via drop-in replacement fuels



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Proud to Pioneer Renewable Propane

First load Neste Rotterdam March 2018

01

bioLPG

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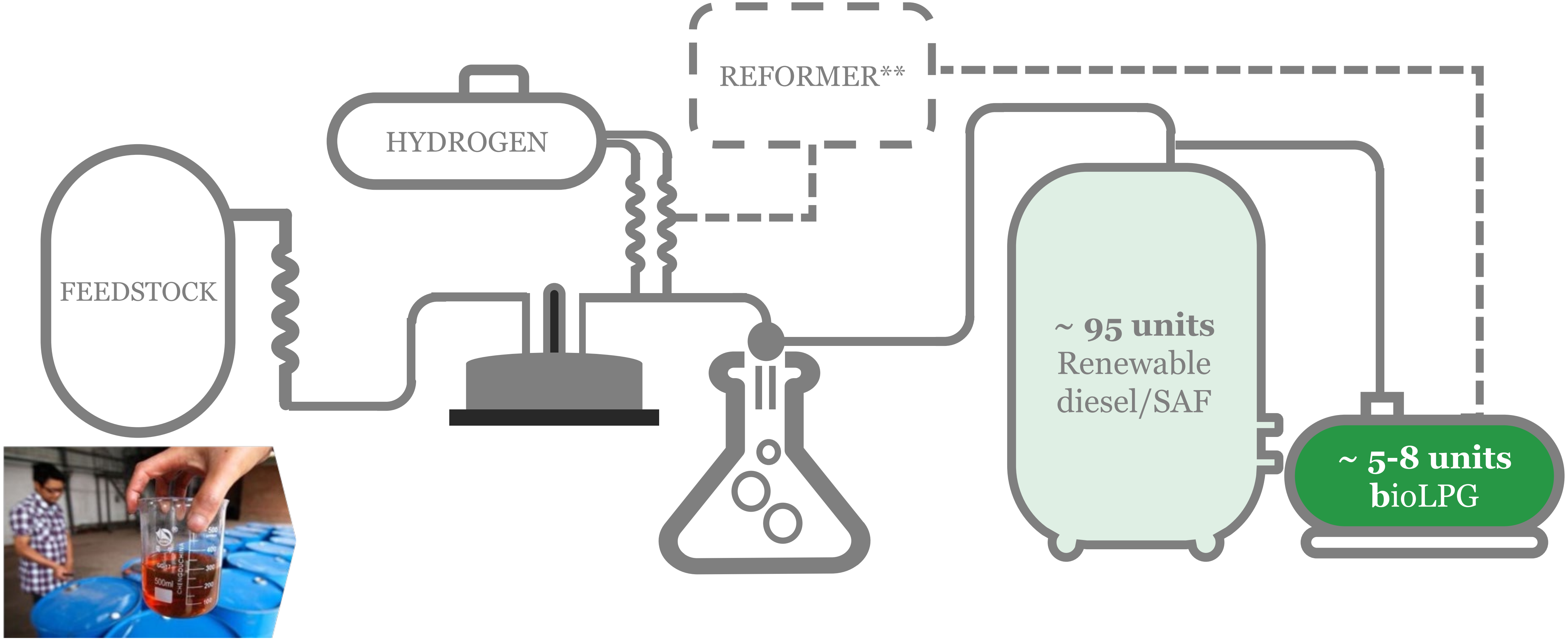
BioLPG as a by-product from HVO/HEFA* renewable diesel/SAF production – but often not isolated



*Hydrotreated vegetable oil/hydrotreated Esters and Fatty Acids
**bioLPG (and bioNaphtha) often converted into hydrogen

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The technical challenges facing the renewable fuels sector – On-Purpose Production

Ideal Feedstock

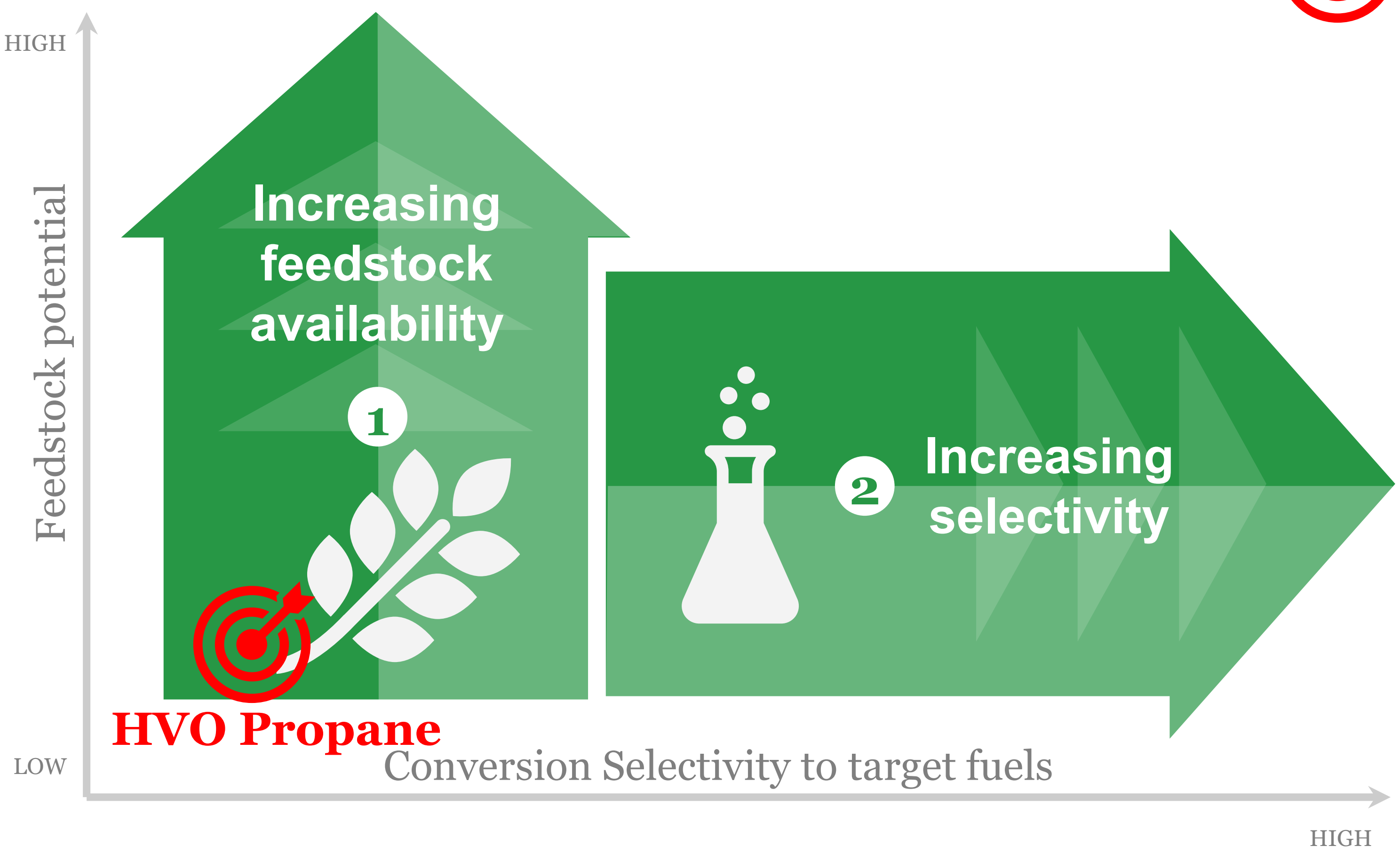
Cheap!

Available at a point source

Liquid or gaseous

Non-food

High energy content



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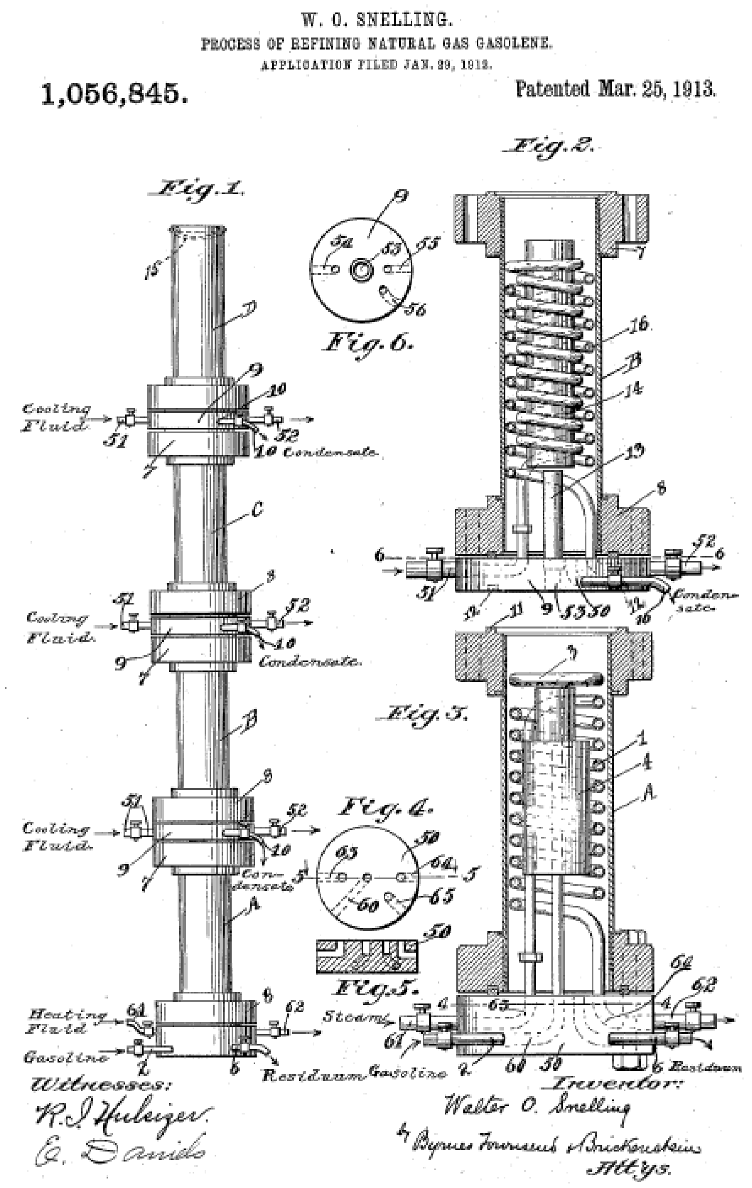
A brief history of On-Purpose Production

On-purpose production of propane was first performed by Dr Walter O. Snelling in around 1910

The “natural gas gasolene” he was using to fuel his Model T Ford was evaporating too quickly

He subsequently invented a distillation technology to isolate LPG, selling the patent it to the company that ultimately became ConocoPhillips

Although the LPG industry went from strength to strength, very little new on-purpose production technology was developed during the next 100 years!



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>24 R&D Partners

Around the World

GTI Energy
Ethanol to LPG Scale-up

LanzaTech
Novel Pathways to LPG

Illinois Institute of Technology
Electrochemical conversion of CO2 and H2 to propane

Penn State University
Non-thermal plasma conversion of CO2 and H2 to propane

University of Bahia
Biomass dewatering with DME

Universidade Federal de Minas Gerais
Conversion of agricultural residues to propane

Propeq
Negative carbon intensity ethanol optimization

University of Santa Caterina
Butyric Acid to Propane

Universidade Federal Rio de Janeiro
LPG from plastics

Universidade Federal Fluminense
Ethanol to LPG

SA/DE consortium
Syngas to LPG

Queens University
LPG from Volatile Fatty Acids

University of York
Trans-methylation of ethylene

University of Ulster
Microbial Production of Propane

University of Manchester
Catalytic cracking of plastic wastes to LPG

Aston University
Butyric Acid to Propane

Drochaid Research
Various

University of Amsterdam
CO2 + H2 to LPG

University of Brescia
Syngas to LPG

Mumbai Institute of Chemical Technology
Aqueous Phase Reforming of Sewage Sludge to BioLPG

National Institute of Technology Calicut
BioLPG from Rice Straw

EnzymeTree
Microbial production of propane

Furukawa Electric/Astomos
Propane from biogas

= **Broad Programme R&D Partner**

= **R&D Partner**

...and more on the way...

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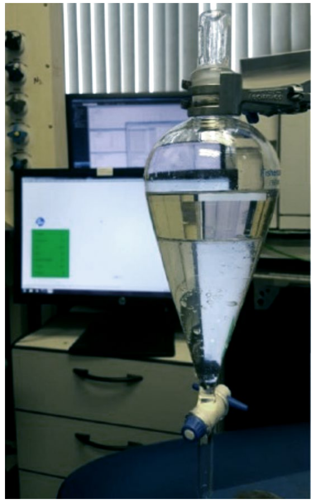
On-Purpose Route to renewable LPG from bioethanol (TRL 4)



*Aromatics
Benzene
Toluene
Ethyl-Benzene
Para-Xylene
1-ethyl-3-methyl benzene
1,2,4 trimethyl benzene
1-methyl-2-isopropyl-benzene

- Ethanol to Hydrocarbon route based on modified Methanol to Gasoline Process
- Catalyst screening has identified viable pathway from to produce LPG together with aromatics in a 2:1 ratio
- Deactivation by coking inhibited by using proprietary catalyst
- Working towards pilot-scale development from 2025
- 2026+ we anticipate commencement of development of a 10ktpa demonstration plant
- Mono-aromatics have potential to be qualified as ASTM SAF
- Hydrogen free!
- Ethanol market currently in rapid growth (1st generation market size in 2021 ca. 80M tonnes)

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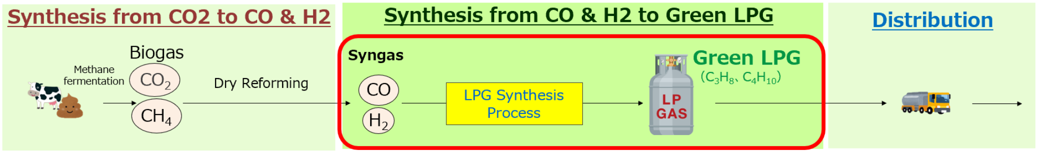
On-Purpose Route to renewable propane from Anaerobic Digestion biogas



LPG yield over 30% & C3 selectivity over 80% are achieved.

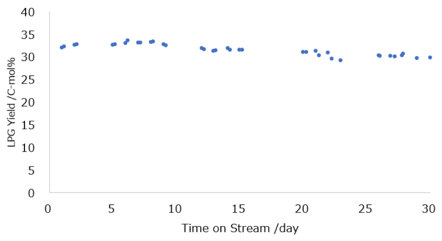


Fig.1 LPG yield vs lifespan

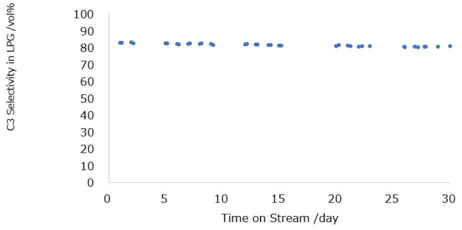
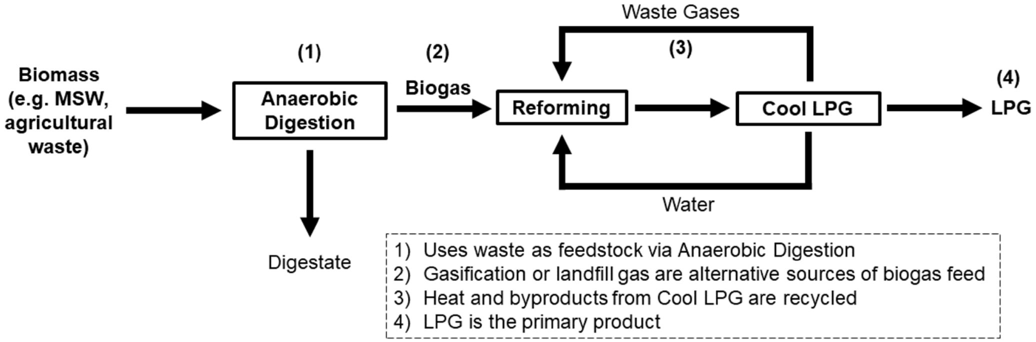


Fig.2 C3 selectivity vs lifespan



BioLPG for Clean Cooking in Sub-Saharan Africa: Present and Future Feasibility of Technologies, Feedstocks, Enabling Conditions and Financing; Chen et al Energies 2021, 14(13), 3916

FURUKAWA ELECTRIC GROUP

Astomos Energy

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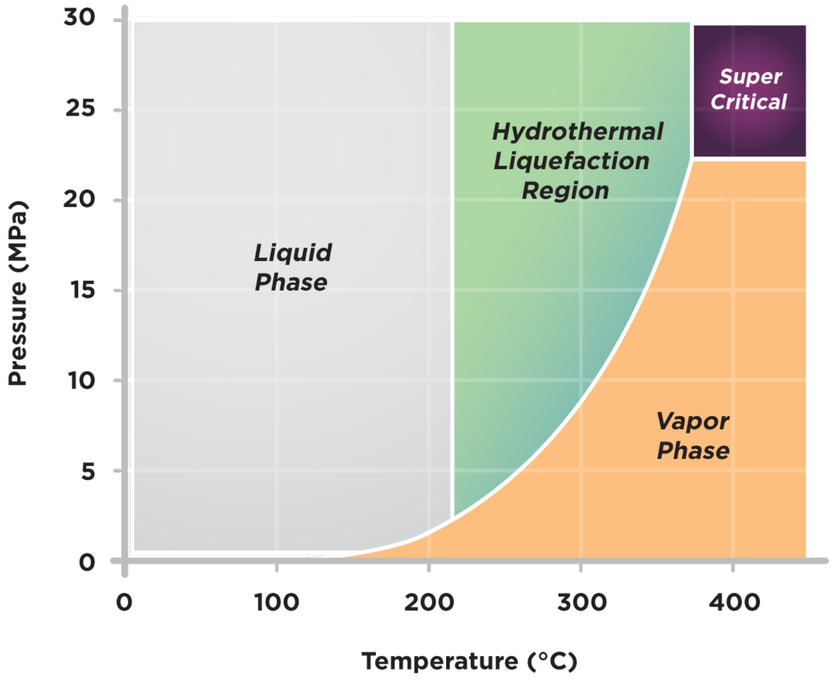
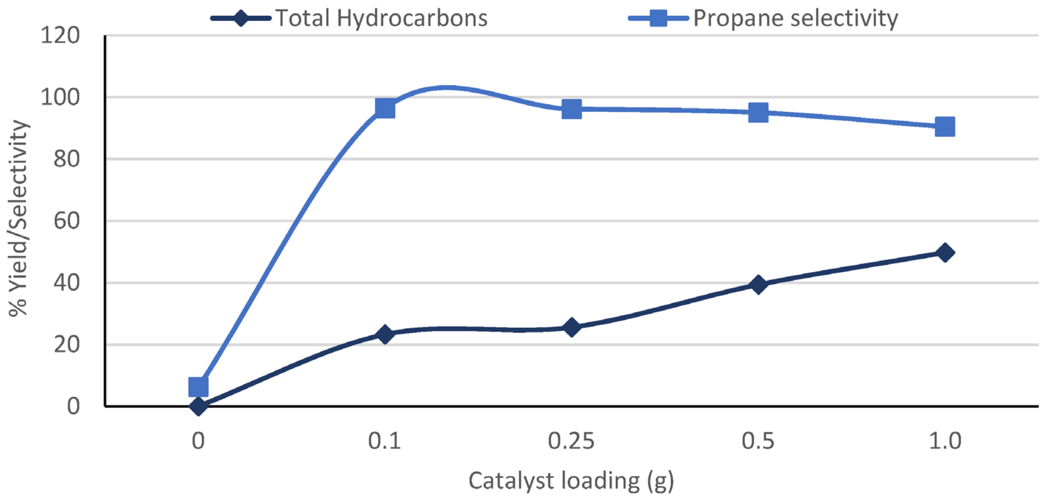




- 95% hydrocarbon selectivity to propane
- Ease of separation
- CO2 capture-ready (low-/negative-carbon)
- Similar results with n-butanol
- Hydrogen free!

Future **Challenges**

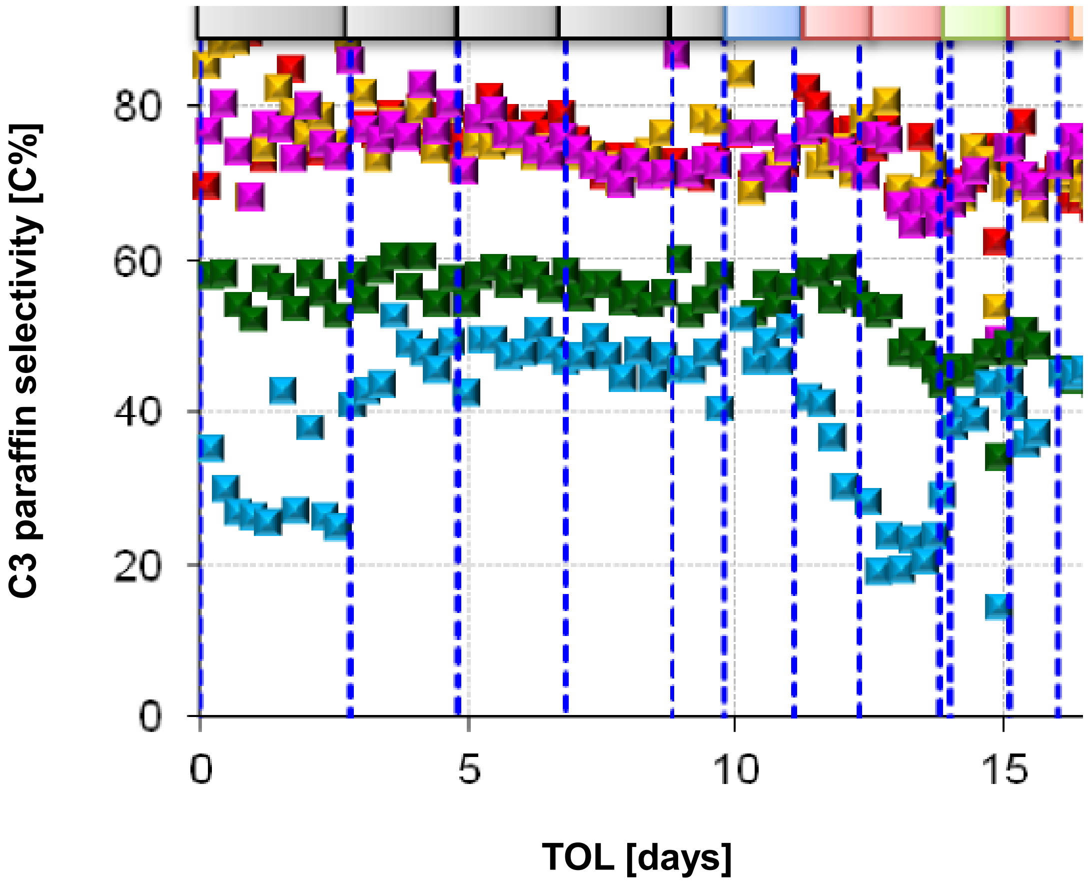
- Switch from a batch to a continuous process
- Process Scale-up
- Identify Earth-abundant catalysts
- Deployment of ABE process for feedstock

Parametric Study of Pt/C-Catalysed Hydrothermal Decarboxylation of Butyric Acid as a Potential Route for Biopropane Production, Razaq et al, Energies 2021, 14(11) 3316

On-Purpose Route to renewable propane from CO2 and hydrogen – “e-Propane” (TRL 2)

- Colours represent distinct catalyst formulation
- The results are for single pass conversion
- Every jump indicates the results of a different experimental condition
- The reaction conditions are comparable to typical Fischer Tropsch conditions
- CO2 conversion is around 10 – 15 %
- C3 is mainly paraffins (upto 80% selectivity)
- As expected CH4 was also produced
- H2:CO2 ratio barely affects the selectivity
- Syngas also a viable feedstock
- Also being investigated by CO2MOS EU Project and others

Using H_2 and CO_2 as the feed (H_2:CO_2 ~ 3-4)



SHV Energy – unpublished results

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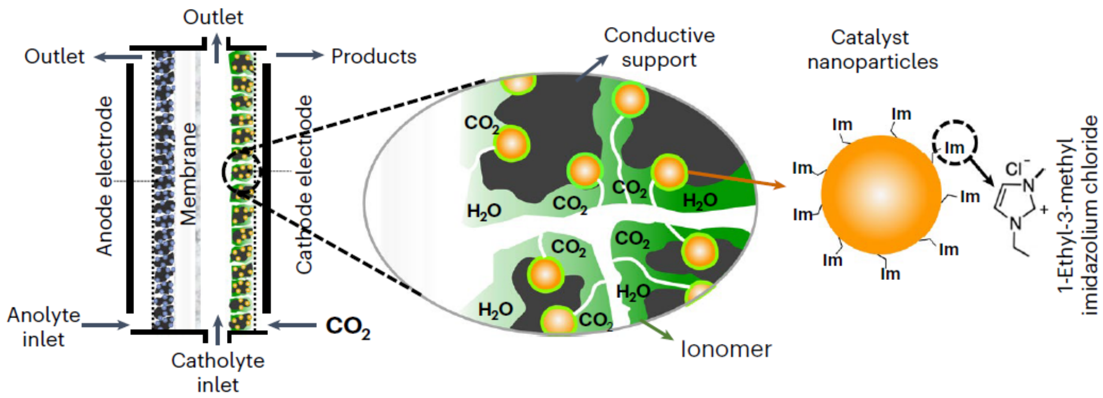
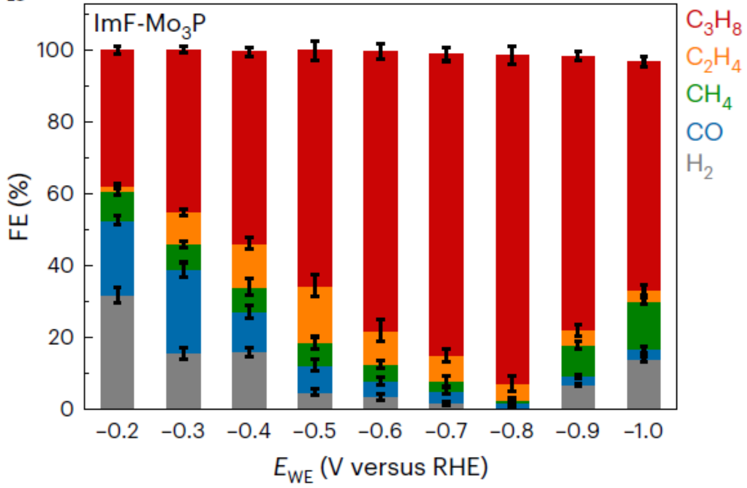
Electrochemical reduction of CO2 to e-Propane (TRL2+)





nature energy

Article

https://doi.org/10.1038/s41560-023-01314-8

Imidazolium-functionalized Mo_3P nanoparticles with an ionomer coating for electrocatalytic reduction of CO_2 to propane

Received: 1 March 2022

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Mohammadreza Esmaeilirad[1,5], Zhen Jiang[2,5], Ahmad M. Harzandi[1], Alireza Kondori[1], Mahmoud Tamadoni Saray[3], Carlo U. Segre[4], Reza Shahbazian-Yassar[3], Andrew M. Rappe[2] & Mohammad Asadi[1]

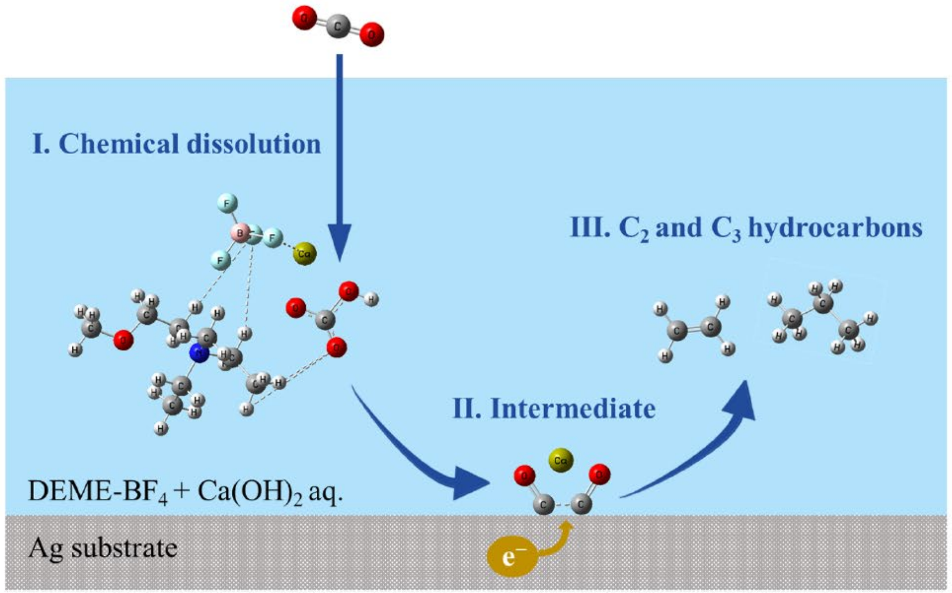

Fig. 9. Process of electrochemical synthesis of C_2 and C_3 hydrocarbons from CO_2 on pure Ag electrode in DEME-BF_4 containing $Ca(OH)_2$ aqueous solution at room temperature.

Saya Nozaki[a], Yuta Suzuki[b], Takuya Goto[a,*]

Electrochimica Acta 493 (2024) 144431

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Conclusions

- A range of viable on-purpose routes to renewable propane are under advanced development and gradually becoming a main-stream R&D topic
- A significant opportunity for the industry to deliver a direct drop-in replacement fuel
- The (LPG) market size is comparable to aviation fuel (300ktpa)
- Engagement of LPG sector to collaborate with technology developers is a major opportunity
- The fastest route to decarbonisation is defosilisation
- Enough feedstock to replace existing and future market

For the latest developments come to Cape Town!

Shiguang Li from GTI Energy - Membrane Reactor for Production of Renewable Liquefied Petroleum Gas from CO_2 and H_2

Seyed Emad Hashemnezhad and Jude Onwudili from Aston University - Kinetics of hydrothermal reactions of n-butanol over Pt/Al_2O_3 catalyst for biopropane production

Miguel Ángel Sánchez García from Futuria Fuels - On-Purpose production of propane from a novel feedstock

Tiana Mathew from University of Cape Town - Use of non-PGM catalyst for the conversion of DME to Green Liquid Fuel Gas

Luiz Daniel da Silva Neto from Universidade Federal da Bahia - Energy for all: perspective of BioDME production in Brazil

Candace Eslick from University of Cape Town - Process modelling and catalyst optimisation for renewable LPG synthesis

Ricardo Lopes de Souza Júnior from Copa Energia and Federal University of Rio de Janeiro - Catalytic conversion of glycerol into Renewable Liquid Gas (RLG)

Dr.Yogesh Joshi of GREEN FUTURES, INC - Oxygen Free Syngas Generation for Cheaper r-DME Production

Thomas Philip Starucka of Universidade Federal de Santa Catarina (UFSC) - Perspectives and technical analysis of a biorefinery plant for butyric acid production from soybean hulls

Ignacio Verdugo of Empresas Gasco and Universidad Tecnica Federico Santa Maria - Electric synthetic liquified gas (e-LG) combustion properties assessment

Masayuki Fukushima of FURUKAWA ELECTRIC GROUP - Green LPG from Biogas

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