Decarbonising trucks, trains, boats and planes
REA's Renewable Transport Fuels Group

Other RFNBO gases, are they a good idea, can their costs come down and which are most promising?

Dr Keith Simons

December 2019

SHV ENERGY
BioLPG

SHV Holdings trading group
Privately owned, *international* in reach and *local* in focus

SHV Energy is part of SHV Holdings, a family owned Dutch trading company, regarded as one of the world's largest private trading groups.

SHV Holdings is a highly diversified company

SHV Holdings employs around 60,000 people in 60 countries.

Est. 1896

60 Countries

60,000 Employees

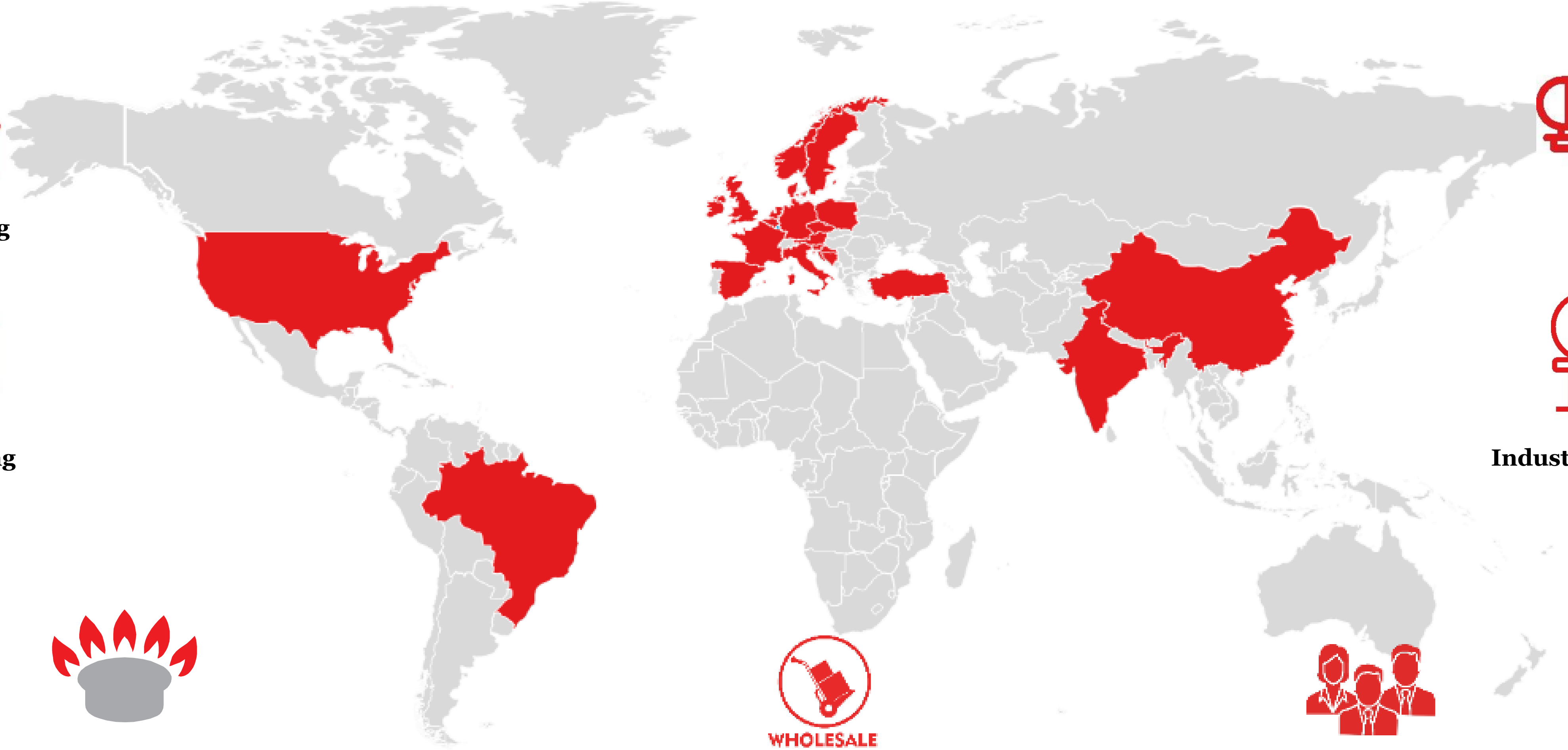
€20B Turnover 2017

SHV Energy : Our global brands

PRIMAGAS SUPERGASBRAS PRIMAGAZ iPRAGAZ CALOR LIQUIGAS GASPOL 喜威 SUPERGAS LIQUIVEX PRIMAGAS PRIMA LNG BUTAN PLIN PINNACLE BALCAS

Cooking

Heating



Transport

Industrial Processes

~5.4 million mT retail sales
~10.4 billion gallons

WHOLESALE

~5,1 million mT 3rd party
~10 billion gallons

17000 employees

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Source: SHV Energy 2017 report

Our value chain / logistics

01 Extraction & production

02 Upstream transportation

03 Storage

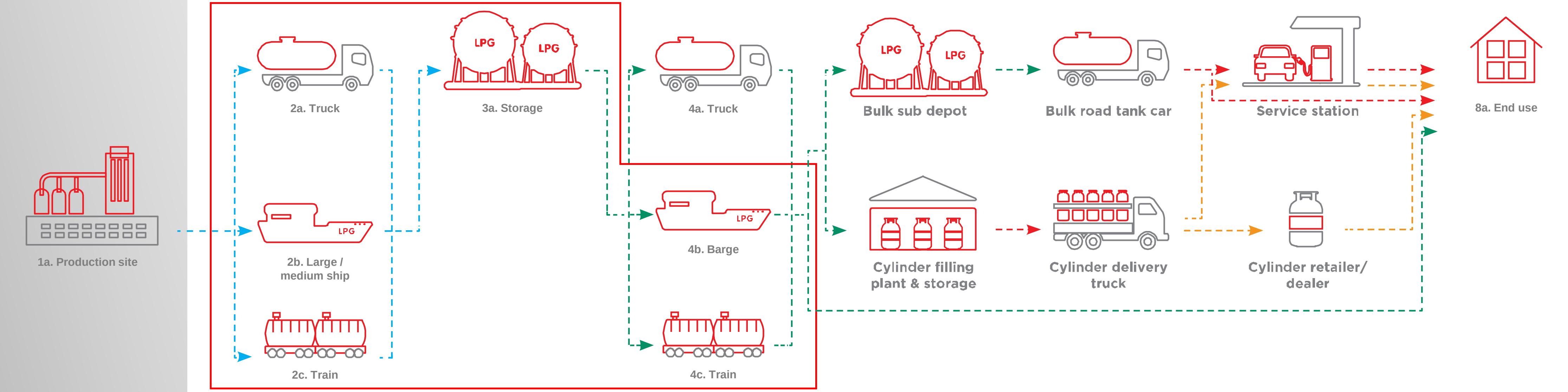
04 Primary transportation

05 Midstream processing

06 Secondary transportation

07 Retailing

08 End Use



Integrated SHV ENERGY SUPPLY & RISK MANAGEMENT
Paris, Vienna, Singapore

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Our product portfolio innovation

The past

Coal

1896

LPG
Propane
Butane

1950

Biomass

2008

The present …

LNG

2013

& the future …

BioLPG
Renewable
Propane

2018

KLM Royal Dutch Airlines SkyNRG SHV ENERGY

2019

SHV ENERGY

Our Vision : Advancing Energy Together

Our commitment : 5 million tonnes of CO_2 reduction by 2025

Our bold ambition : 100% of our energy products to be from renewable sources in 2040

emoss
Driven by innovation

CALOR

UK Rigid Truck Types


2 axle <18te


18-26te 3 axle


8 x 4 tipper 28-32te


2 axle 16te Flatbed


3 axle Concrete mixer


Curtainsider

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Driven by innovation

CALOR

The World's 1st LPG Range-Extended Electric 16te Cylinder truck

Military grade Li-Ion batteries

2 litre **LPG** steady state engine (could also run on CNG)

Plug-in charging (1.5 h @ 44kW)

40 mile EV-only range **<u>with GPS ring-fencing</u>**

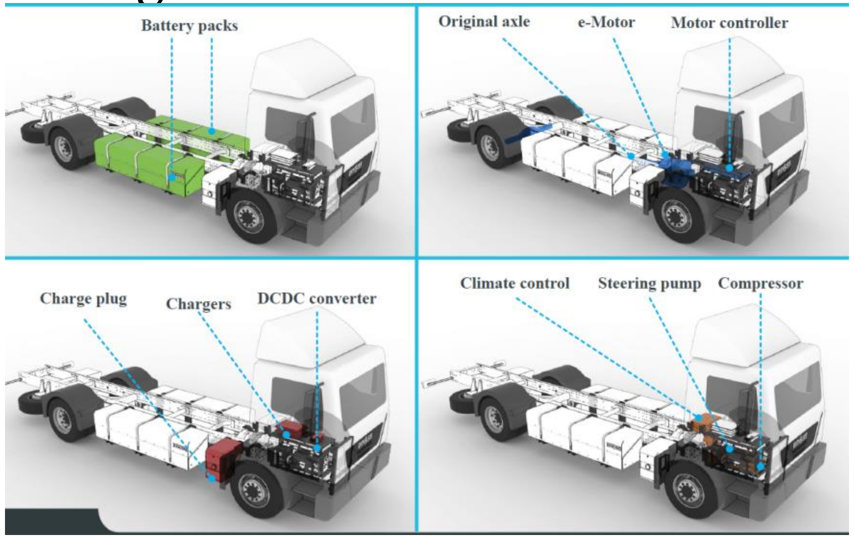
350 mile RE range

Regenerative braking

Cleaner

Quieter (50%)

Lower carbon



CALOR

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Other RFNBO gases…..

(Renewable Fuels of Non Biological Origin)

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Definition of RFNBOs

3.33 RFNBOs are renewable liquid or gaseous transport fuels for which none of the energy content of the fuel comes from biological sources. These fuels are considered renewable where the energy content of the fuel comes from renewable energy sources but excluding bioenergy sources[23]. This means that RFNBOs could be made using electricity and/or heat and/or cold from wind, solar, aerothermal, geothermal or water (including hydrothermal sources, waves and tides). RFNBOs cannot be derived from bioenergy sources and therefore would not be able to be derived from biomass, landfill gas, sewage treatment plant gas or biogases. As the available energy source of RFNBOs comes from the process energy, the input feedstocks must contain no usable energy. In practice this means that the feedstock must be either water and/or carbon dioxide (CO_2).

3.34 The simplest RFNBO is renewable hydrogen (for example from wind or solar power electrolysis) that is directly used in transport applications: either in an internal combustion engine or a fuel cell electric vehicle. A range of other renewable transport fuels can also be generated by reacting this RFNBO hydrogen precursor with CO_2, to produce RFNBO products such as methane, methanol, ethanol, di-methyl ether, petrol, kerosene and diesel.

3.35 If a RFNBO is produced from CO_2, the carbon dioxide can come from waste fossil sources (for example, waste flue gases from coal and natural gas power generation or similar industrial combustion processes), from biological sources (e.g. alcohol fermentation or anaerobic digestion) or from atmospheric or naturally-occurring/geothermal sources.

RTFO Guidance Part One Process Guidance

2019: 01/01/19 to 31/12/19

Moving Britain Ahead

This definition would also allow for ammonia (NH3)

Other RFNBO Gases (Renewable Fuels of Non Biological Origin)

Methane
Dimethyl Ether (via Methanol)
LPG?
(NH_3)

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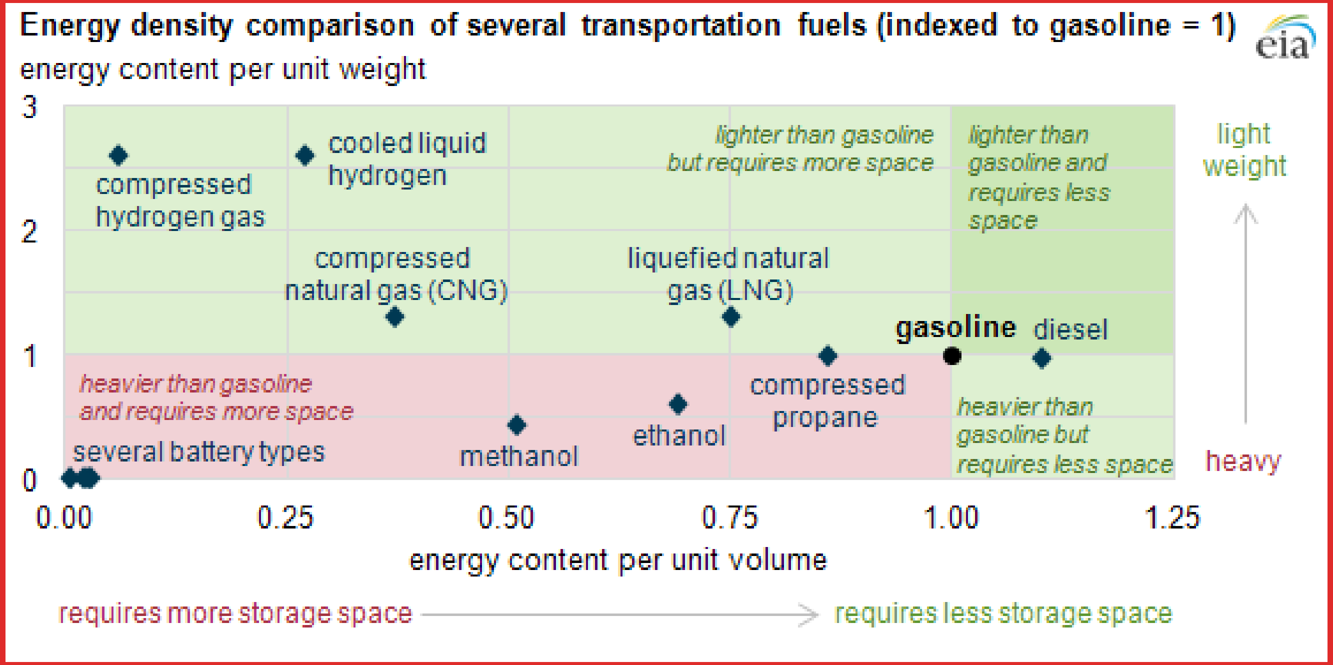
Are they a good idea?

If you don't have a direct need for the energy



If you don't need to store and then transport – Yes!

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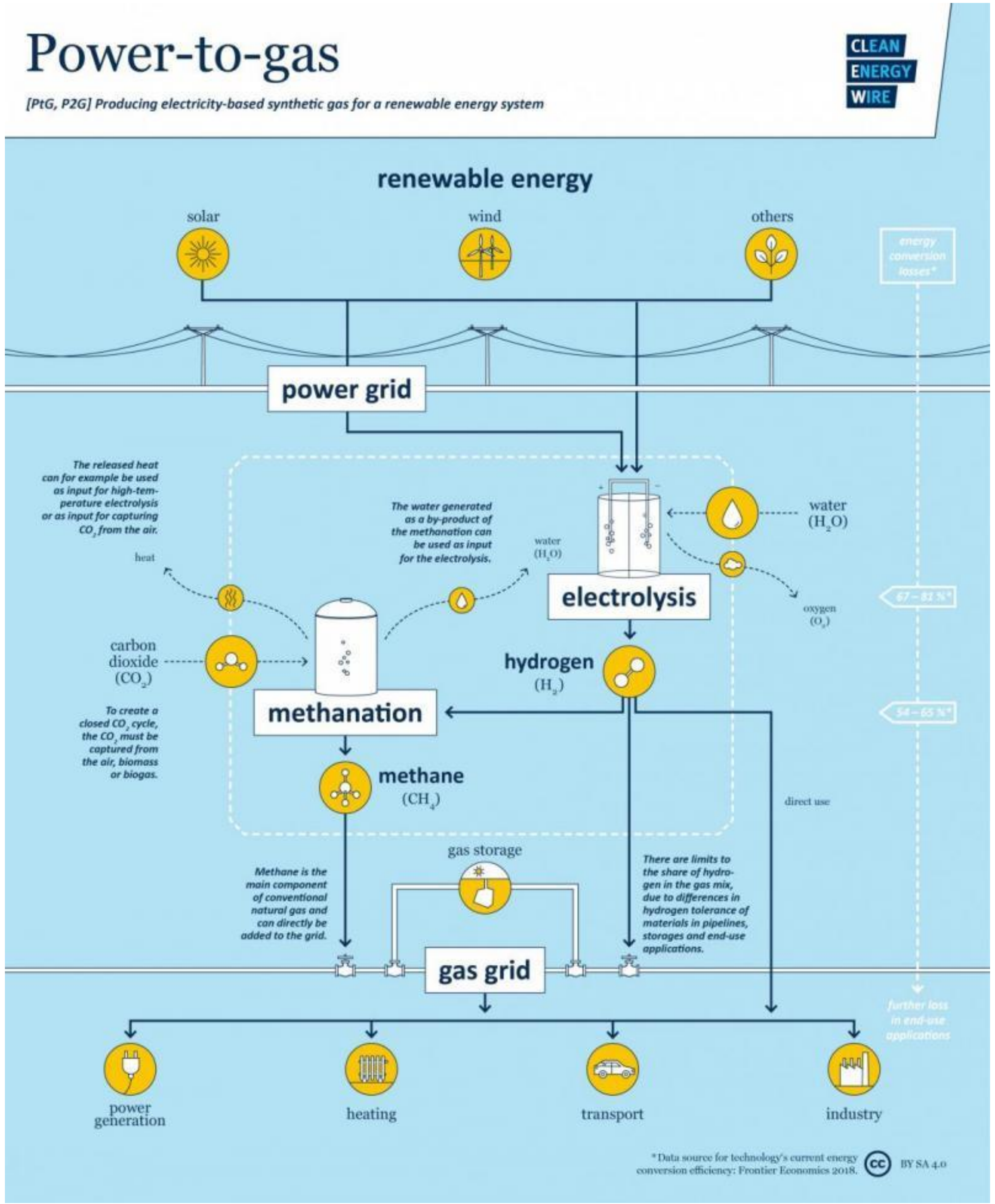
Methanation



Makes a drop-in fuel
Can benefit from surplus electricity
Can store energy over a long period of time
Transports well
Doesn't require biomass
Can re-use a lot of (downstream) existing infrastructure
Many demonstration projects

However
– after electrolysis only about 67-81% of energy remains
- After methanation only about 54-65% of energy remains
- Makes expensive water (from water)
- Requires a point source of (clean) CO2
- Not suited to intermittent production

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O_{(g)} \quad \Delta H_{298K} = -164 \frac{kJ}{mol}$$

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Power to Gas - Bioelectrochemical biogas upgrading

N. Aryal et al. | Bioresource Technology xxx (xxxx) xxx–xxx

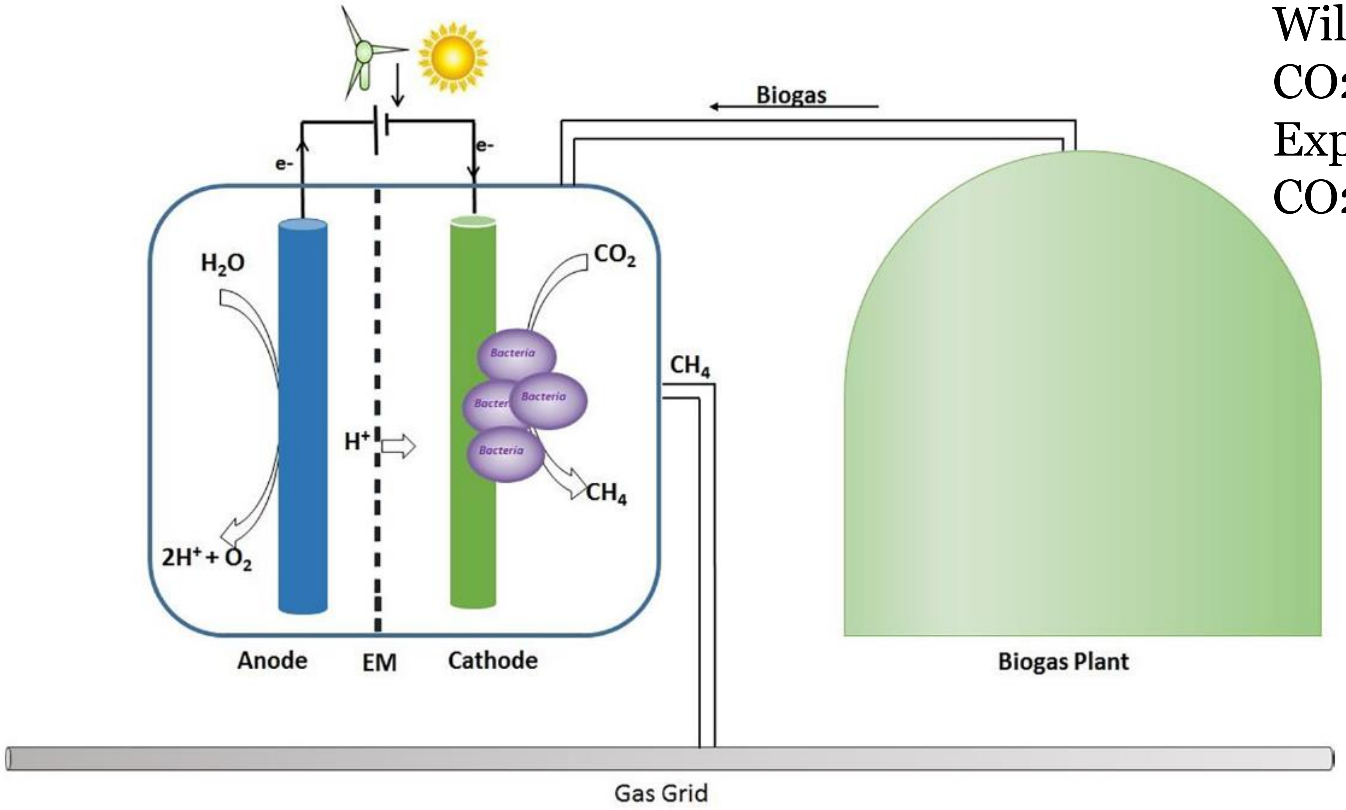

Fig. 3. Bioelectrochemical CH_4 enrichment phenomena discussed in this review, where EM represent Exchange membrane, electrochemical oxidation reaction takes place at the anode to generates O_2 and H^+ and electrochemically active microorganisms utilize the cathode as electron donor and CO_2 from biogas to produce CH_4.

Will the release of biogenic CO2 from biogas be allowed in the future?
Exploit (constrained) electricity to methanate CO2 in biogas in microbial fuel cells

$$CO_2 + 8H^+ + 8e^- \rightarrow CH_4 + 2H_2O$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

Biogas enrichment in anaerobic digestion

N. Aryal et al.

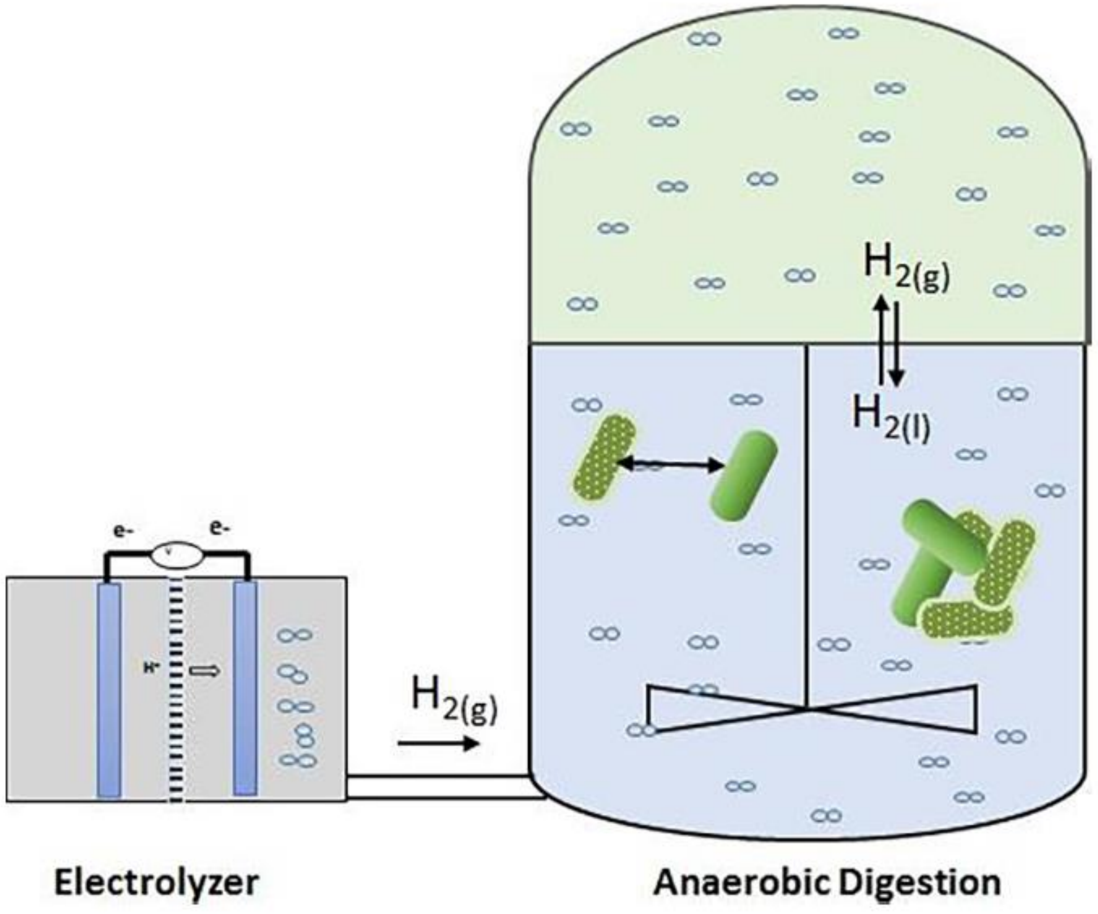

Fig. 2. Hydrogen (H_2) uptake in AD supplied from electrolyzer where "⚯" is $H_{2(g)}$ represents in gaseous phase, and $H_{2(l)}$ in the liquid phase.

Hydrogen from a conventional electrolyser injected into digester and methanates CO2 in biogas

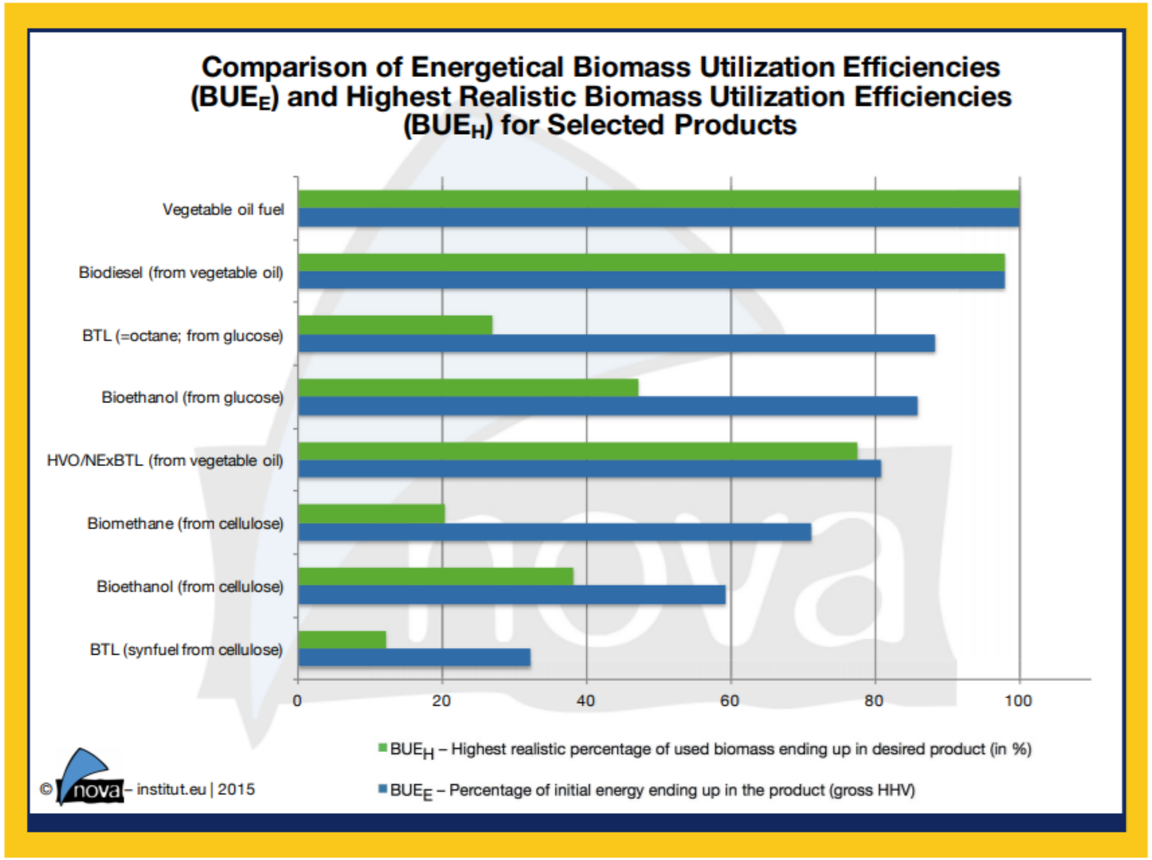

Figure 4: Comparison of Energetic BUE_E with Highest Realistic BUE_H for selected compounds

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Dimethyl Ether (from Methanol)

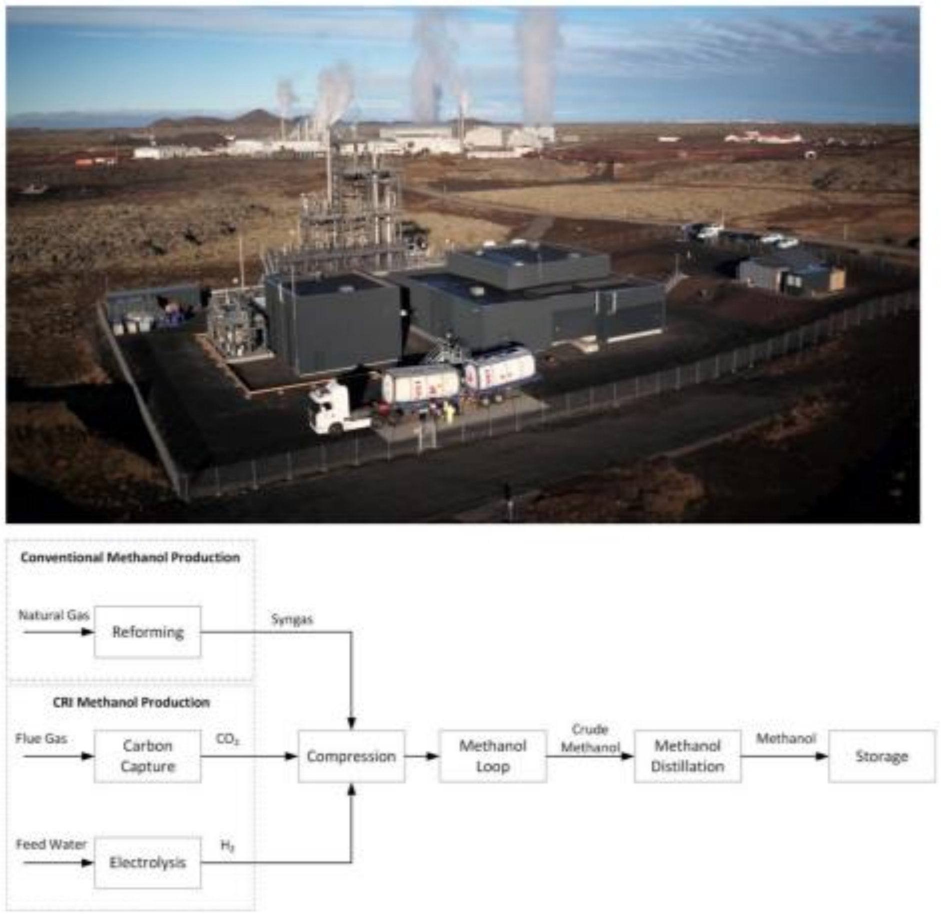


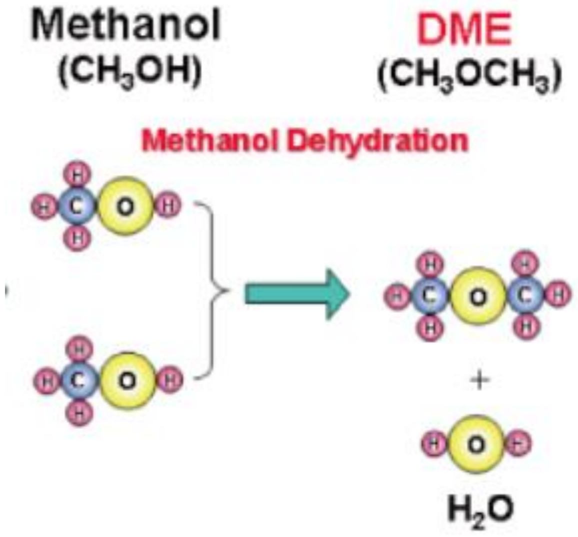
FIGURE 1 | (Top) CRI's George Olah Renewable Methanol plant in Svartsengi, Iceland. (Bottom) Block flow diagram showing the different origins of syngas for the conventional process compared to the CRI process starting from CO_2 pointing out the energy intensive reforming process in the former.

Process Advantages of Direct CO_2 to Methanol Synthesis

Dana S. Marlin, Emeric Sarron and Ómar Sigurbjörnsson*

Carbon Recycling International, Kópavogur, Iceland

Companies such as CRI in Iceland have been pioneering Methanol synthesis from electrolytic hydrogen and CO2 flue gas



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DME has very similar properties to LPG

• DME is promising as Energy carrier from remote resource for high energy intensity by volume and safety aspect.

	Liquid H_2	Liquid Ammonia	Methanol	DME	CO_2
Formula	H_2	NH_3	CH_3OH	CH_3OCH_3	CO_2
Liquid density [kg/L]	0.07	0.7	0.795	0.67	1.1
Boiling point [℃] @0.1Mpa	−253	−33.4	64.4	−25	(−50)*1
Vapor pressure [Mpa] @25℃	—	1.02	0.0129	0.53	(0.7)*1
Energy density by Weight [MJ/kg]	120.8	19.2	21.1	28.8	—
Energy density by Volume [MJ/L]	8.5	13.4	16.8	19.3	—
Explosion limit [%]	4～75	15～28	6.7～36	3.4～27	—
Allowable limit of toxicity	—	25ppm	200ppm	—	—

*1: Marine transportation condition of liquid CO_2

Japan DME Forum

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LPG Synthesis?

Synthesis of C_{2+} hydrocarbons by CO_2 hydrogenation over the composite catalyst of Cu–Zn–Al oxide and HB zeolite using two-stage reactor system under low pressure

Masahiro Fujiwara*, Hiroaki Sakurai, Kumi Shiokawa, Yasuo Iizuka

$$CO_2 + 3H_2 \xrightleftharpoons{\text{Methanol synthesis catalyst}} CH_3OH\ (+H_2O) \xrightarrow{\text{Zeolite}} C_{2+}\ \text{Hydrocarbons}$$

Table 2
CO_2 hydrogenation over Cu–Zn–Al (6:3:1) oxide + HB composite catalysts using two-stage reactor system.[a]

Run	Temp. of first reactor (°C)	Pressure (MPa)	Flow rate (mL/min)	CO_2 conv. (%)	Selectivity (C-mol%)								C_{2+} yield (C-mol%)
					CO	C_1	C_2	C_3	C_4	C_{5+}	MeOH	DME	
1	250	0.98	50	25.3	91.3	0.2	1.4	1.5	1.5	0.3	2.4	1.4	1.19
2[b]	250	0.98	50	20.7	73.2	1.3	1.2	5.9	12.0	1.7	3.1	1.6	4.31
3	300	0.98	50	32.5	90.8	0.3	1.4	2.7	2.7	0.5	1.1	0.5	2.37
4	400	0.98	50	43.2	87.6	0.5	1.4	5.0	4.5	0.5	0.4	<0.1	4.92
5	420	0.98	50	45.9	85.4	0.8	1.3	5.9	5.6	0.6	0.3	<0.1	6.15
6[c]	420	0.98	50	45.8	87.1	0.7	1.3	5.2	4.9	0.5	0.2	<0.1	5.45
7[d]	420	0.98	50	45.8	89.3	0.4	0.6	0.7	1.2	0.3	2.4	5.1	1.28
8[e]	420	0.98	50	45.2	95.2	0.4	0.7	1.6	1.8	0.2	0.1	<0.1	1.94
9[b]	420	0.98	50	25.0	95.7	0.7	1.0	0.2	0.0	0.0	1.8	0.6	0.30
10[f]	420	0.98	50	47.2	77.5	0.9	1.1	9.0	10.2	1.0	0.2	0.1	10.05
11[f]	420	0.98	25	47.8	66.8	1.4	1.7	15.0	13.6	1.3	0.2	<0.1	15.10
12[f]	420	0.5	50	45.2	93.5	0.3	0.5	2.6	2.5	0.4	0.1	0.1	2.71
13[f]	420	0.3	50	43.2	95.3	0.2	0.4	1.8	1.8	0.3	0.1	0.1	1.86

[a] Reaction conditions: catalyst in the first reactor 1 g of Cu–Zn–Al (6:3:1) oxide obtained by calcination at 500 °C for 4 h, catalyst in the second reactor 0.1 g of Cu–Zn–Al (6:3:1) oxide obtained by calcination at 500 °C for 4 h and 0.9 g of HB zeolite (SiO_2/Al_2O_3 = 28.5), 300 °C, 0.98 MPa, H_2/CO_2 = 3, catalytic activity after a time-on-stream of 1 h.
[b] Without the cold trap.

Can their costs come down?

(Competitive) efficiencies

P2G Pathways	Technologies	Current	Long Term
Power to Natural Gas End-users	Electrolyser, Low pressure hydrogen storage/compression, Injection to pipeline	59–83%	64–86%
	to heat for residential	52–76%	56–79%
	to micro-CHP	40–72%	55–74%
	to large scale gas turbines	18–26%	23–31%
Power to Renewable Content in Petroleum Fuel	Electrolyser, Low pressure hydrogen storage/compression	55–83%	59–86%
Power to Power	Electrolyser, Low pressure hydrogen storage/compression, fuel cell	17–40%	27–43%
Power to Seasonal Energy Storage to Electricity	Electrolyser, low-pressure compression, underground storage, Transmission pipelines, Natural gas-based power plants	16–24%	22–29%
Power to Hydrogen for zero—emission transportation	Electrolyser, low-pressure compression and storage, high-pressure compression for refueling station.	50–79%	54–82%
Power to Seasonal storage for Transportation	Electrolyser, low-pressure compression, underground storage, hydrogen separation technologies, high-pressure compression	36–68%	43–66%
Power to Renewable Natural Gas (RNG) to Pipeline ("Methanation")	Electrolyser, Low-pressure energy storage and compression, Methanation reactor, Gas Clean-up, Injection of Renewable Natural Gas to the Natural Gas Pipeline	40–63%	45–65%
Power to Renewable Natural Gas (RNG) to Seasonal Storage	Electrolyser, low-pressure compression, Methanation reactor, Gas Clean-up, Underground storage, Injection of RNG to the Natural Gas Pipeline	34–60%	43–58%

Source: Transition of Future Energy System Infrastructure; through Power-to-Gas Pathways. *Energies*. (2017)

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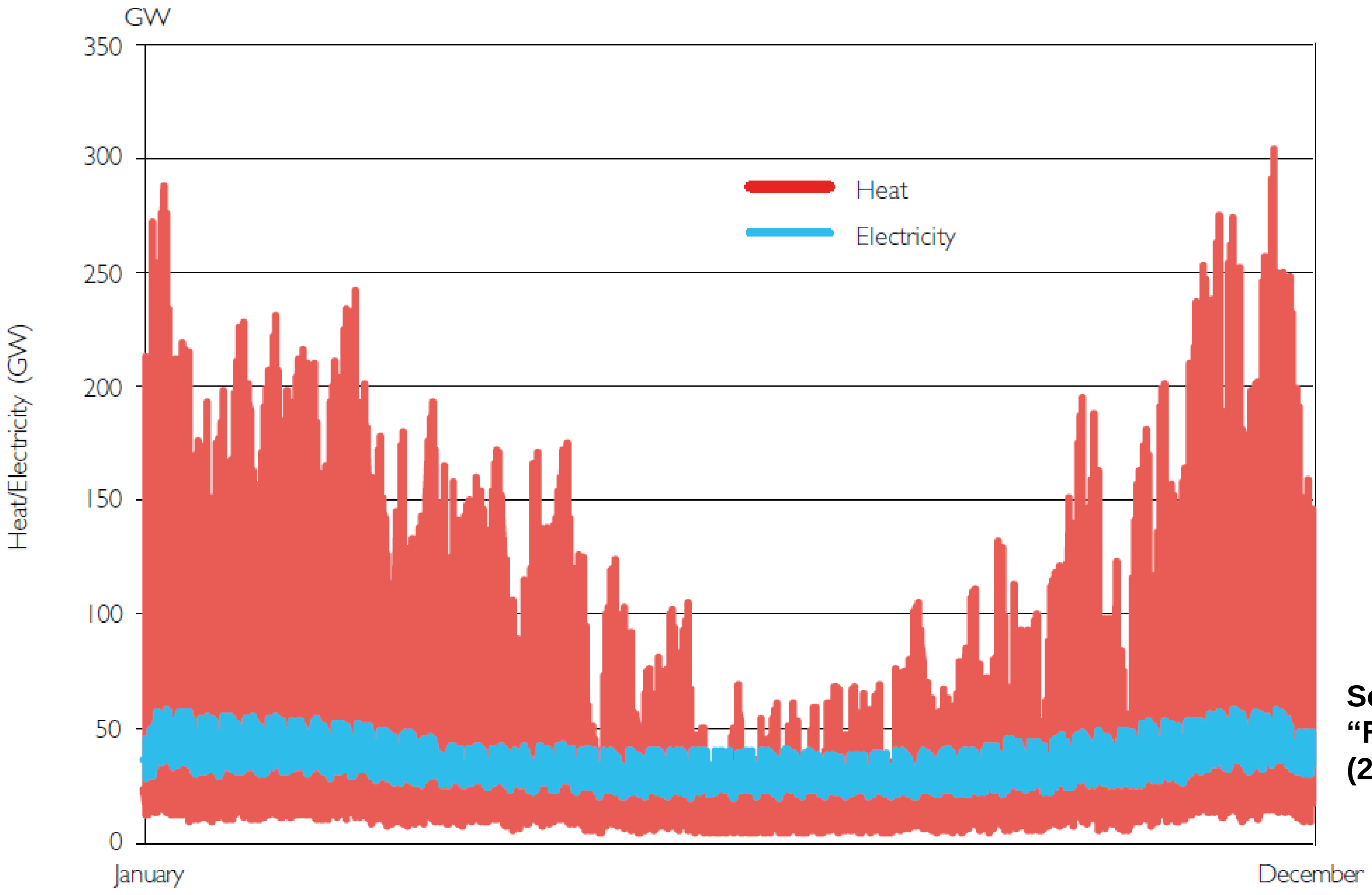
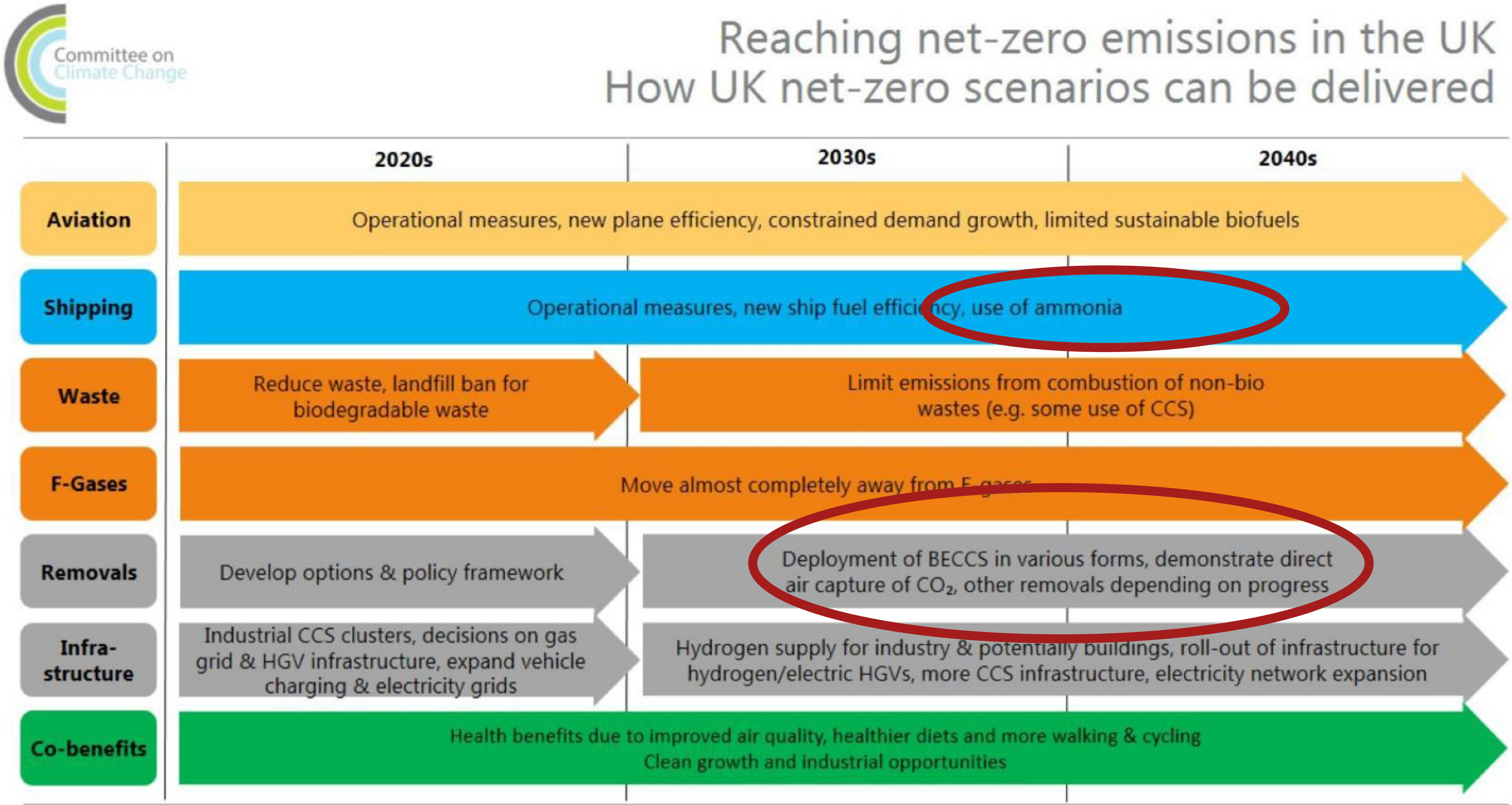
Heat & electricity demand variability across the year

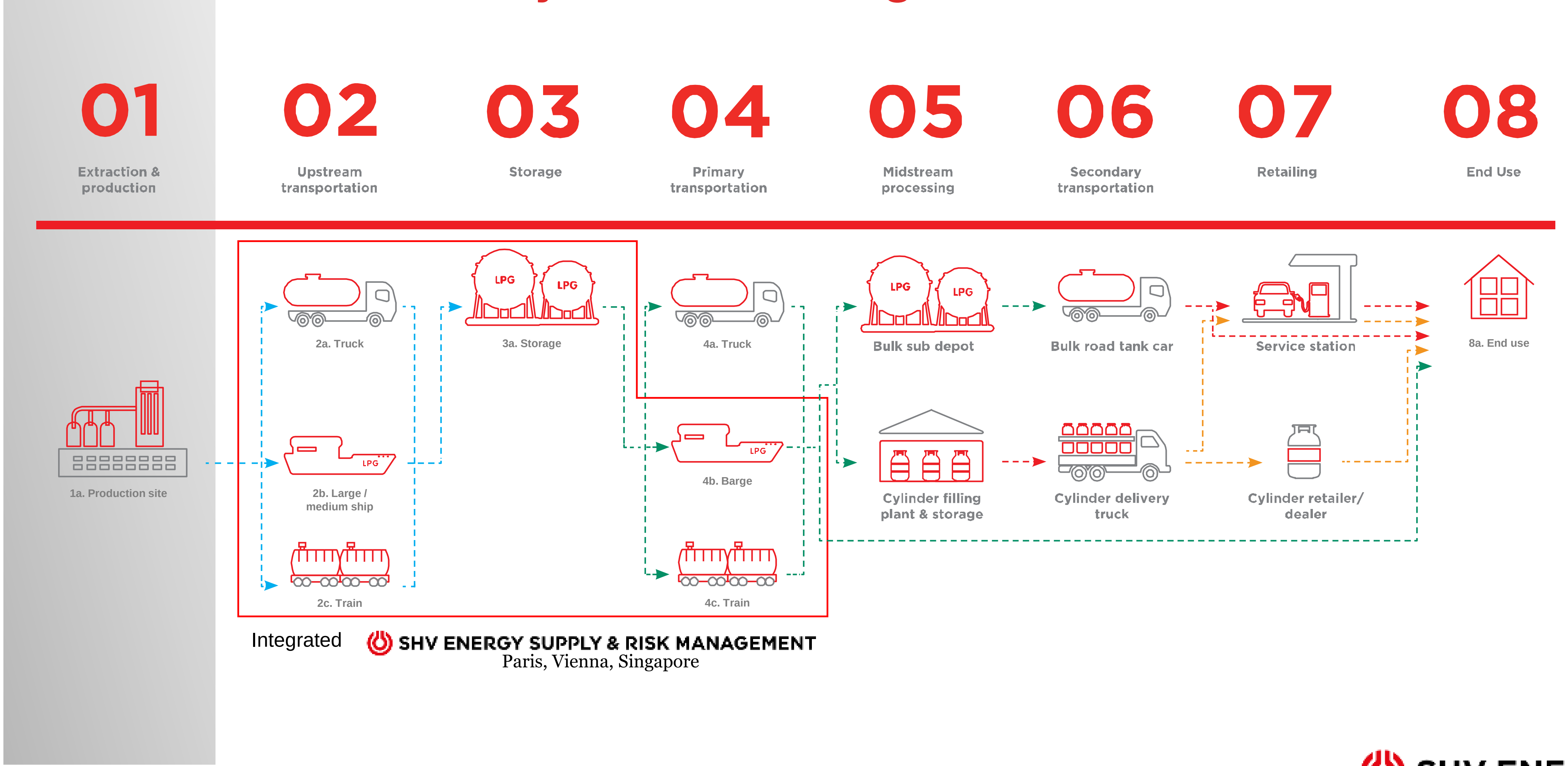


Source: DECC "Future of Heating" (2012)



DAC: Having a strategy requires which relies on overcoming the Second Law of Thermodynamics is bad policy

Exploitation of exisiting upstream and downstream infrastructure is a major cost saving



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Other developments

Massive expansion of (seasonal) renewable electricity and load/frequency response via hydrogen generation will drive down upstream costs
Expansion of CCS/CCU will again drive down costs

Require policy which encourages the fair exploitation of recycled carbon ***and carbon monoxide***

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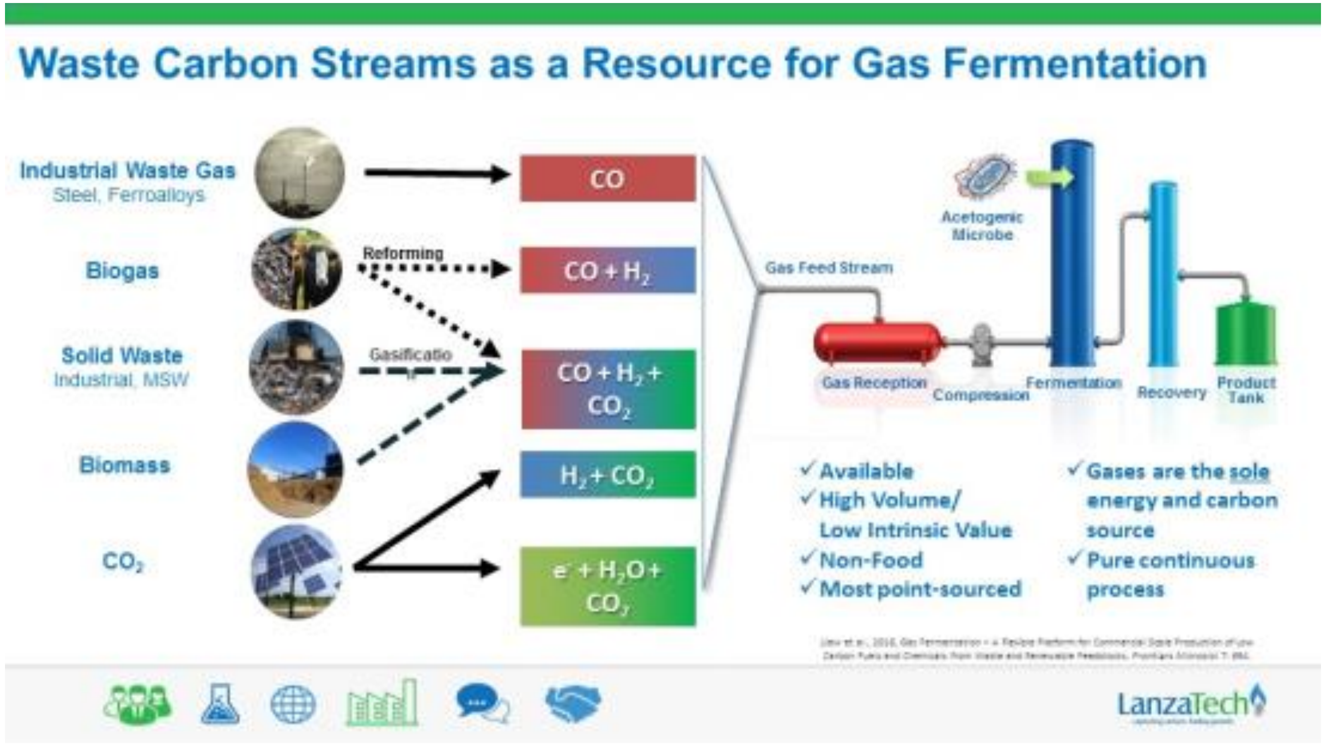
RFNBO definition too narrow

CO2 has no intrinsic energy content
CO2 needs to be captured
Hydrogen/electrons used to make ***carbon monoxide*** – this is the actual fuel
Maximisation of carbon monoxide is key
Further hydrogen then used to make fuels
Enables access to large point sources of carbon (and hydrogen) together with electrolytic hydrogen



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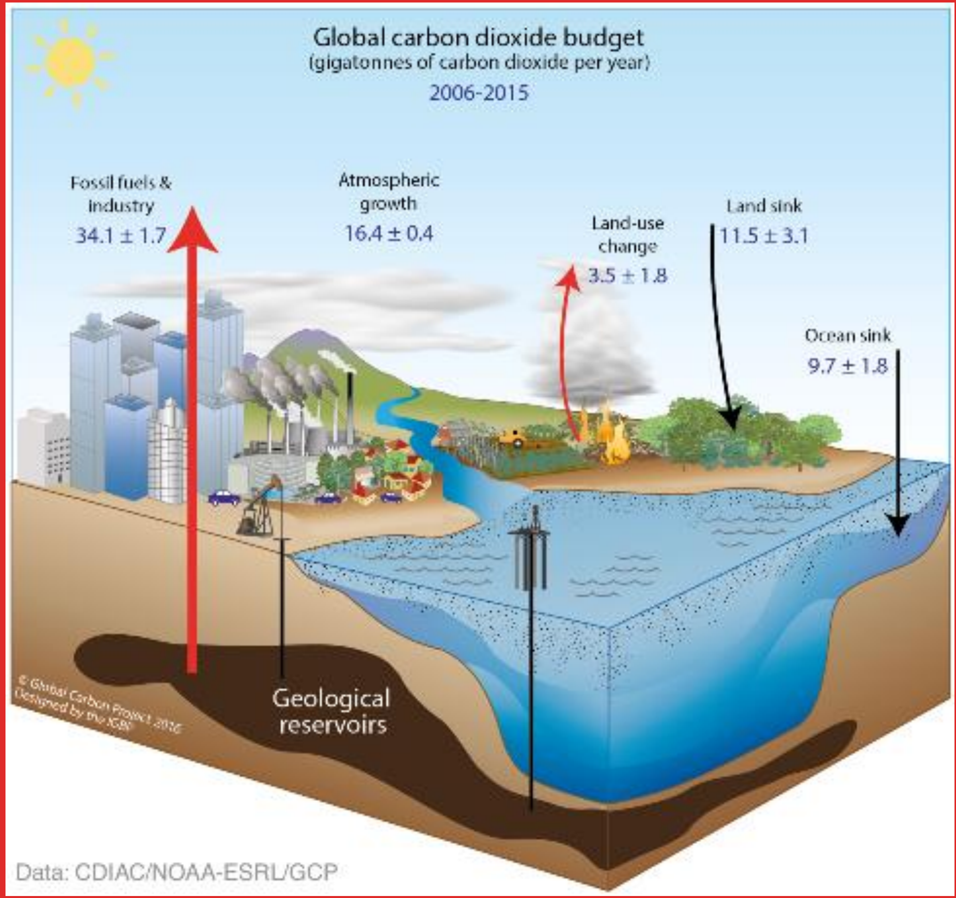
Are they any good?

Climate science tells us that bread today is just as valuable as jam tomorrow

Quick wins with ***drop-in*** replacements have long-term cumulative benefit
(can we please forget about DAC?)



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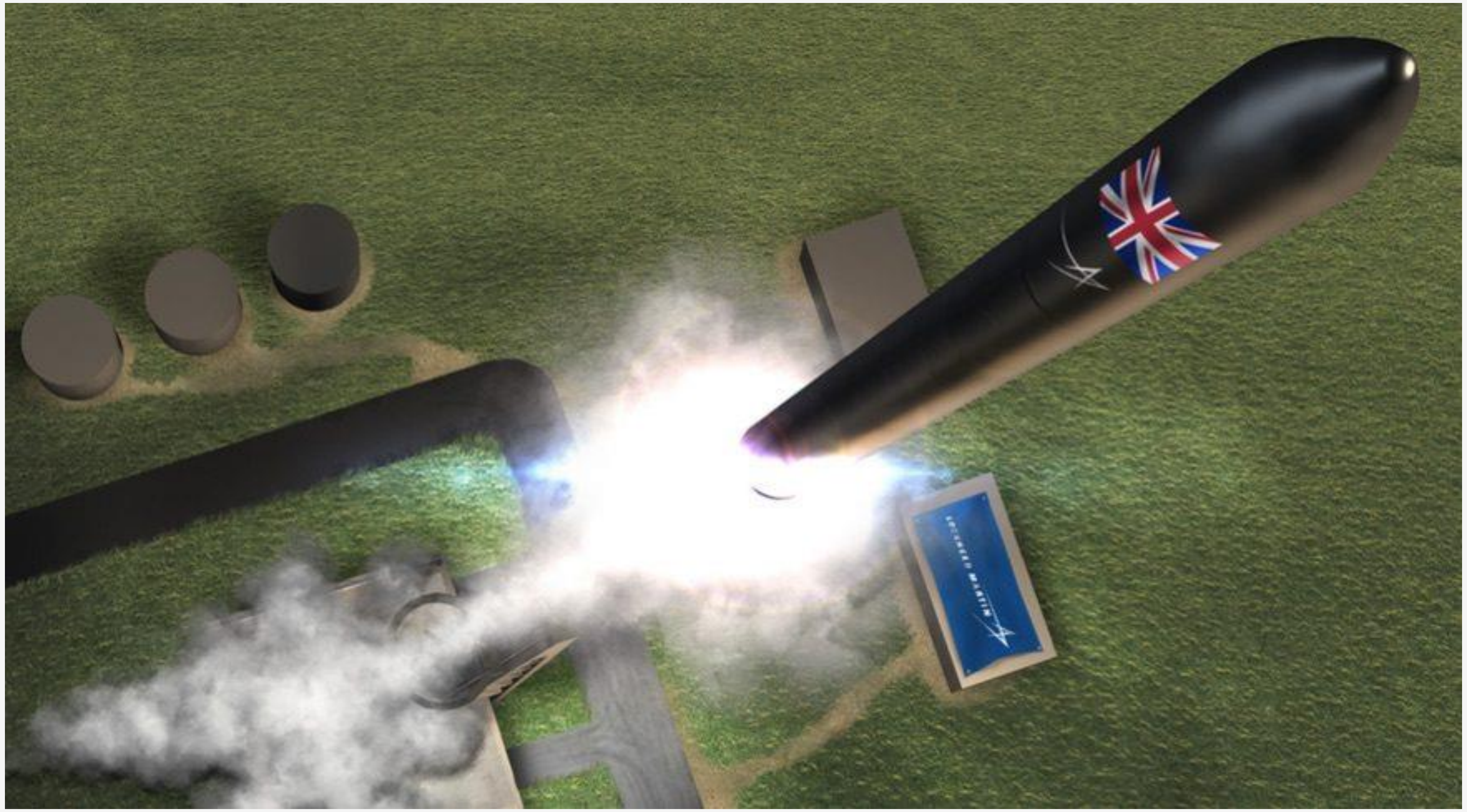
Biopropane to Infinity & Beyond!



Lockheed Martin and Orbex to launch UK into new space age

July 16th 2018 – Farnborough International Air Show

“Their orbital launch vehicle, called Prime, will deliver small satellites into Earth’s orbit, using a single renewable fuel, ***bio-propane****, that cuts carbon emissions by 90% compared to hydrocarbon fuels.”*

https://www.gov.uk/government/news/lockheed-martin-and-orbex-to-launch-uk-into-new-space-age

CALOR

Together in Electric Dreams

Thank You!

Keith.simons@shvenergy.com