CO_2 to jet: Context and Concepts

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TUCK foundation event

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The e-fuel scene

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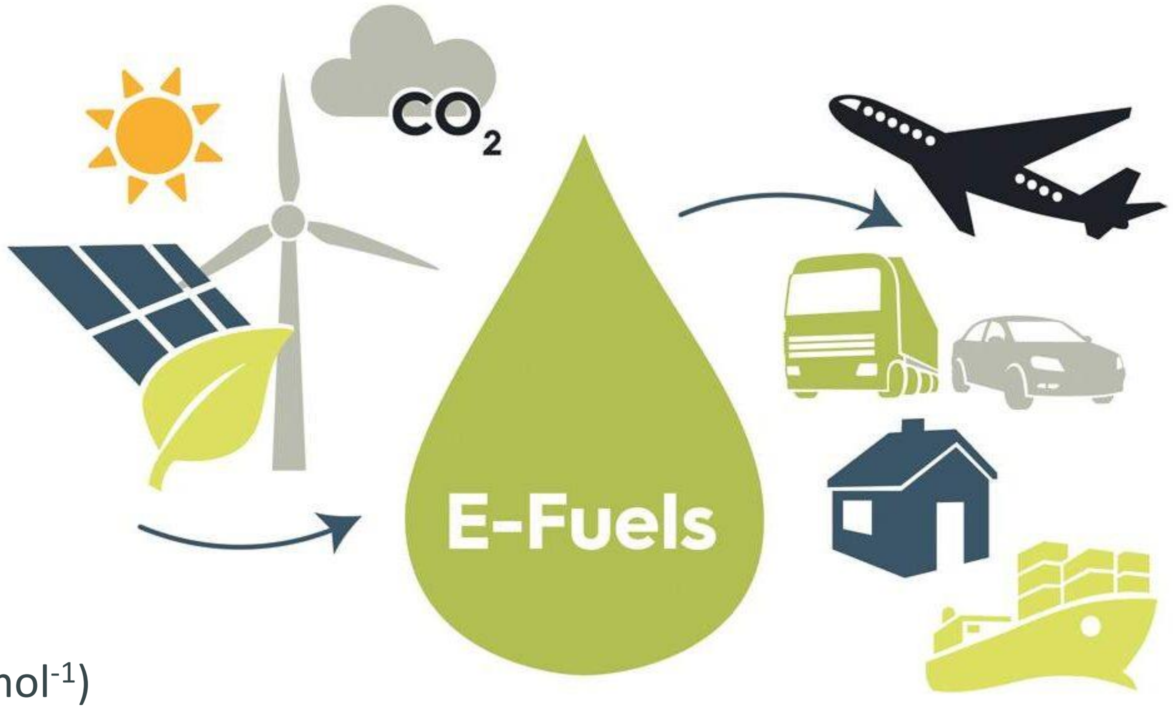
'**Electrofuels**, also known as **e-fuels** or **synthetic fuels,** are a type of **drop-in replacement fuel**. They are manufactured using captured **carbon dioxide** or carbon monoxide, together with hydrogen obtained from **sustainable electricity** sources such as wind and solar power'.

C=O bond strongest of double bonds
Need for green hydrogen

High energy requirement

CO2 & SUSTAINABILITY
R&D LINE

methanol	$CO_2 + \mathbf{3H_2} \leftrightarrows CH_3OH + H_2O$
ethylene	$2CO_2 + 2H_2O \leftrightarrows C_2H_4 + 3O_2$ (**1,412** kJ mol^{-1})
paraffins	$xCO_2 + \mathbf{(3x+1)H_2} \leftrightarrows C_xH_{2x+2} + 2xH_2O$



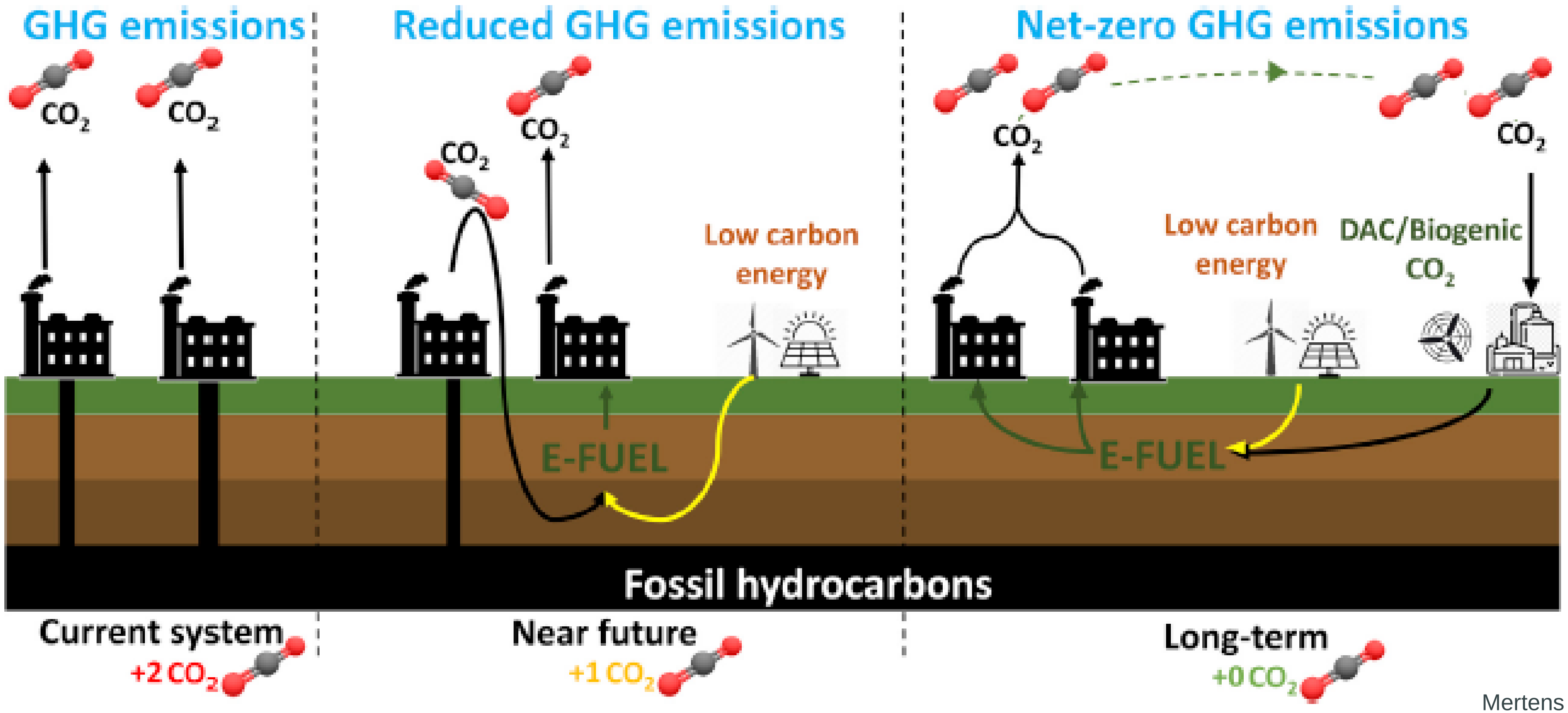
ltaerea.com

e-Fuels for climate mitigation

Potential to **avoid the use of fossil carbon**

Only makes sense if produced from **renewable energy**

Best applied to sectors difficult to abate, e.g. **long-haul transport**



Mertens et al. – Joule 2023

e-Fuels in EU guidelines

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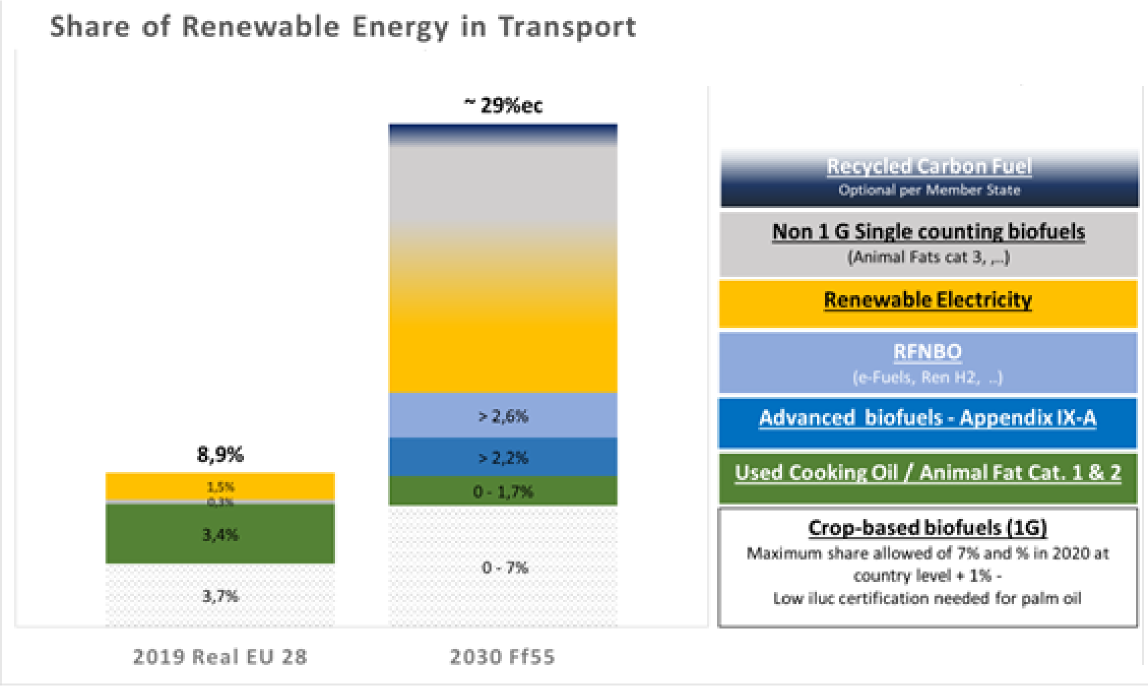
Fit for 55 Package – Policy proposal to achieve a 55 % reduction in GHG emissions by 2030 compared to 1990

Renewable Fuels of Non-Biological Origin (**RFNBOs**) incentivized → renewable electricity, green hydrogen, e-fuels

13 % emissions reduction for transport sector, emphasis on **marine and aviation transport**



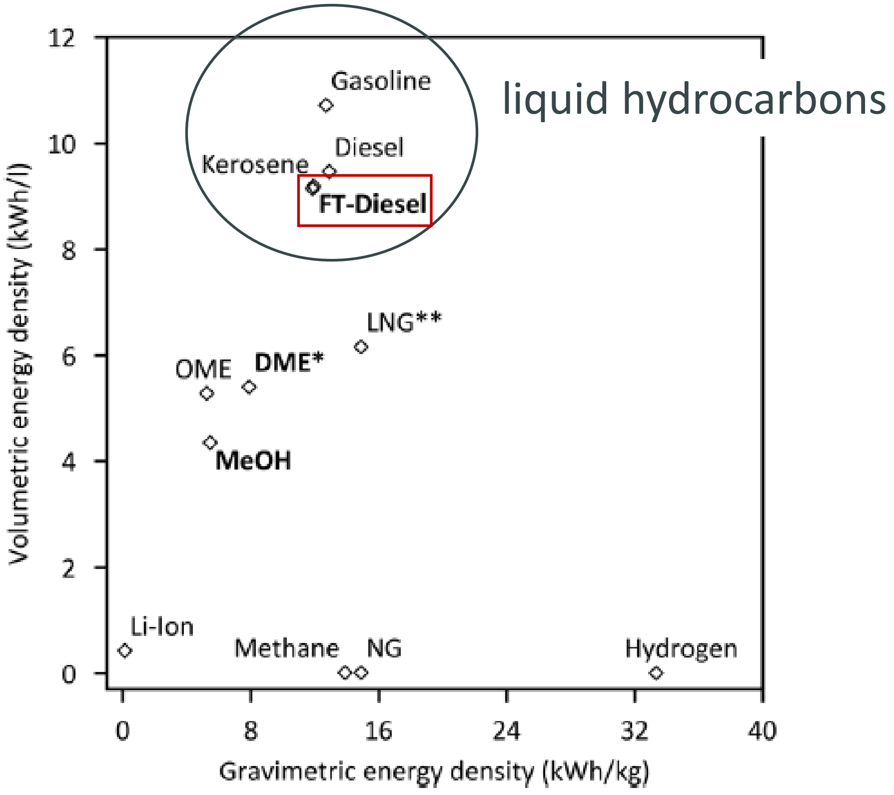
FF55 Package

year	SAF	e-jet
2025	2	--
2030	5	0.7
2035	20	5
2040	32	8
2045	38	11
2050	63	28

RFNBO acknowledged if **GHG savings > 70 %**

e-Fuels for aviation: e-jet

Need to approach **energy density and cold-flow properties** of A-1 Jet fuels



Dieterich et al. – Energy Environ Sci 2023

7 SAFs approved for **up to 50 % blends**
more than a dozen pathways pursuing certification

ASTM[1] approved pathways		Blend limit
FT	Fischer-Tropsh Paraffinic Kerosene (FT-SPK)	50%
HEFA	Hydroprocessed Esters and Fatty Acids (HEFA-SPK)	50%
SIP	Hydroprocessed Fermented Synthesized Isoparaffins	10%
FT-A	FT SPK with Aromatics	50%
ATJ	Isobutanol and Ethanol to Jet Synthesized Paraffinic Kerosene	50%
CHJ	Catalytic hydrotherolysis jetfuel	50%
HHC	Biological derived hydrocarbons from algae	10%

[1] ASTM D7566

eligible for e-jet

e-Jet as 100 % drop-in fuel : a challenge

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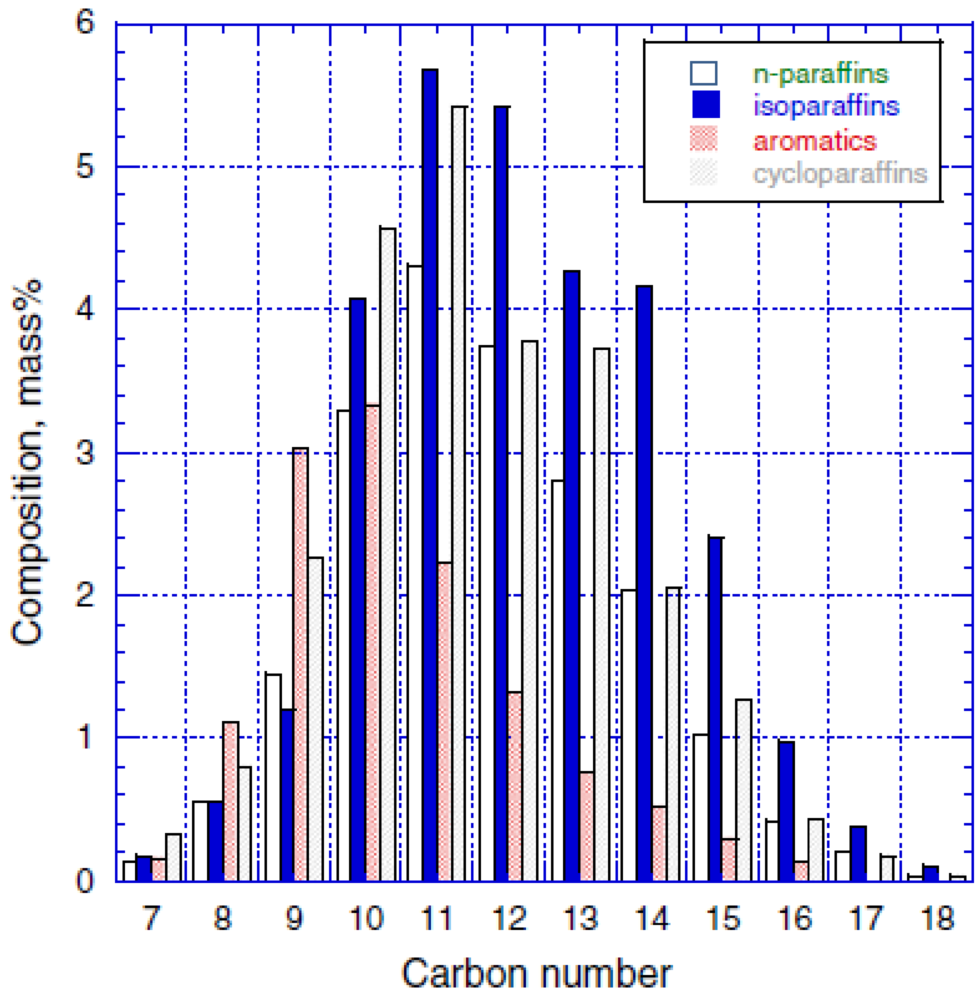
conventional jet fuel composition:



Colket et al. – AIAA J 2017

Jet A and jet A-1 contain **8-25 vol% aromatics**

Need for CO_2 conversion technologies to:

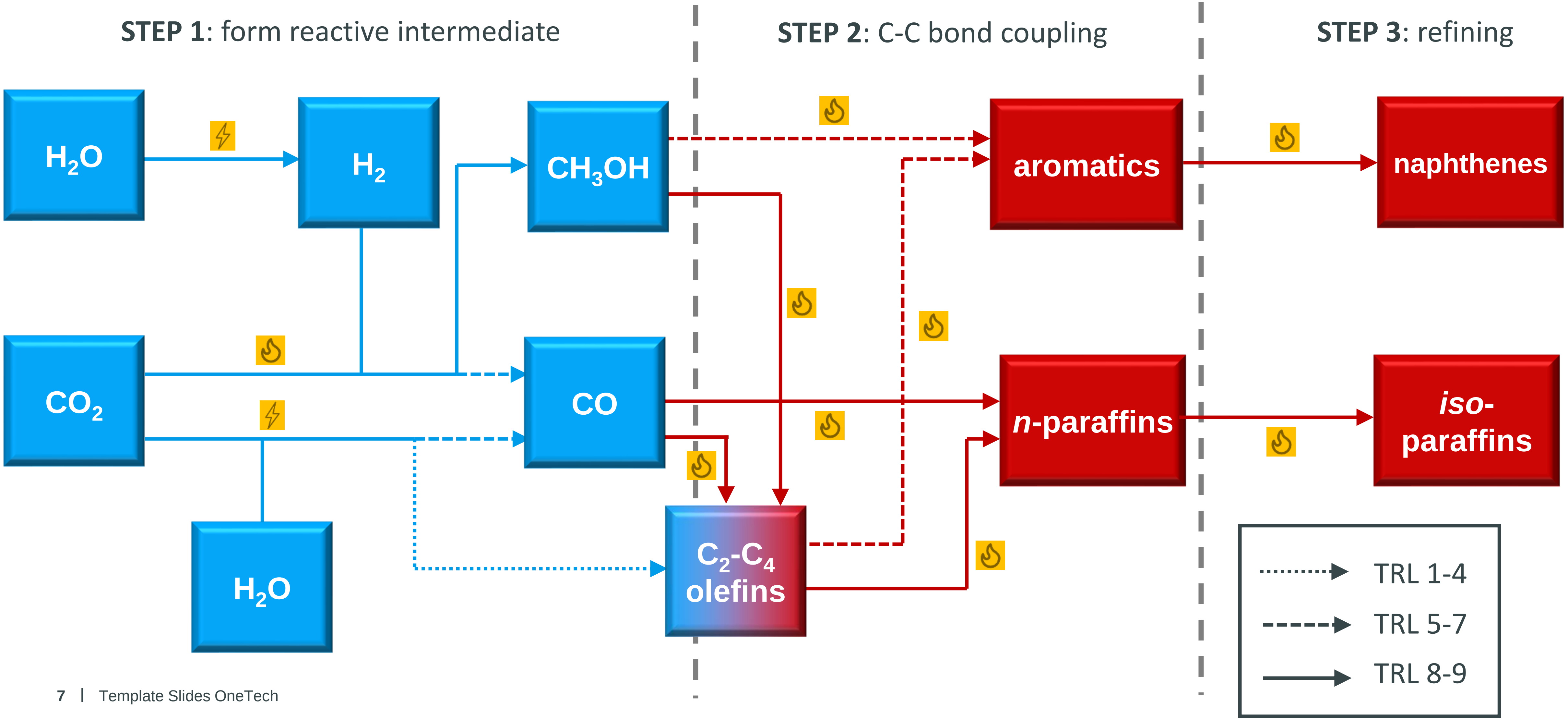
- *n/iso*-paraffins in C_7-C_{18} range
- multi-substituted aromatics

} Blended in correct amounts

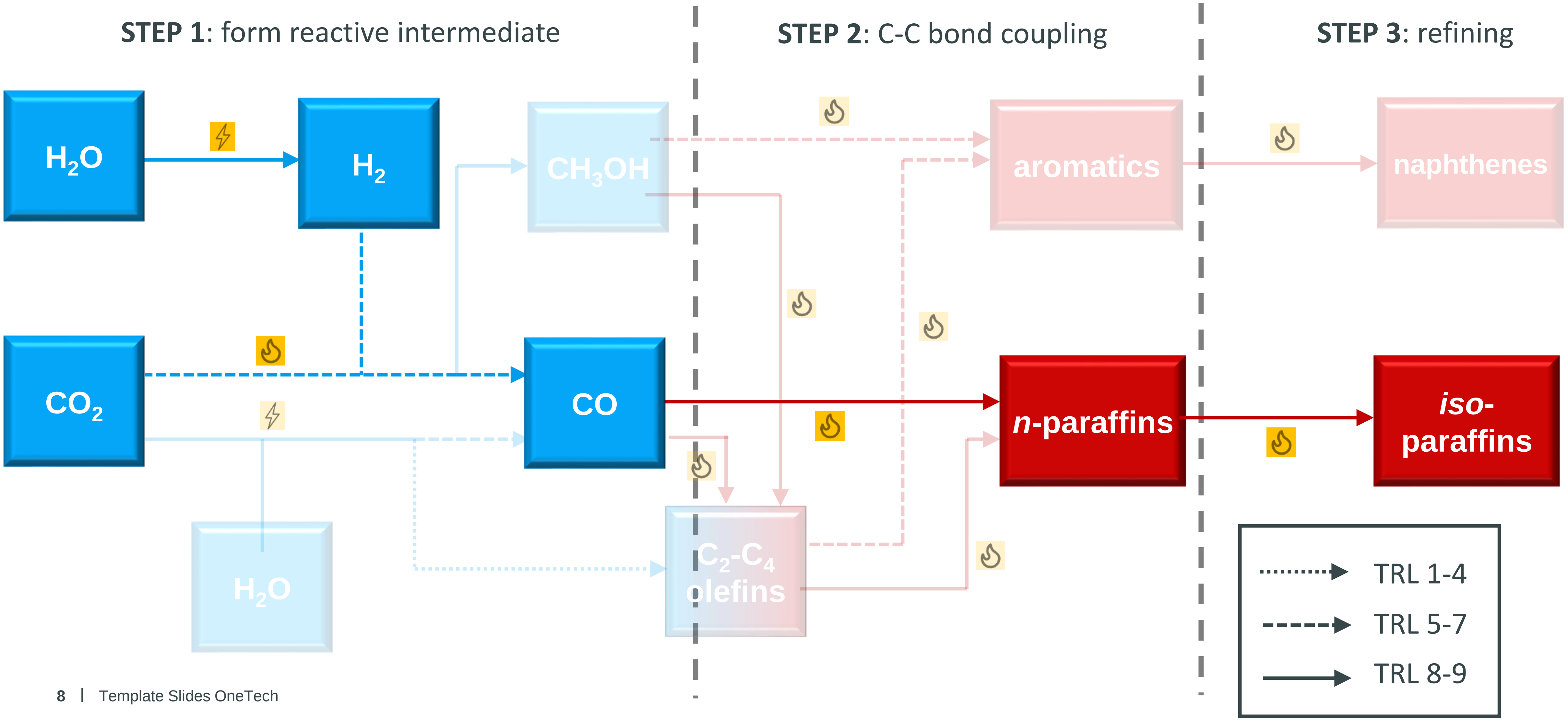
jet fuel property	*n*-parrafin	*iso*-paraffin	naphthene	aromatic
energy content				
gravimetric	+	+	0	–
volumetric	–	–	0	+
combustion quality	+	+	+	–
low-temperature fluidity	– –	0/+	+	0/–

Chevron Aviation Fuels 2007

CO_2 to e-jet : a multitude of pathways



CO_2 to e-jet : a multitude of pathways



CO_2 to e-jet: Focus on Fischer-Tropsch route

syngas production

water electrolysis

$H_2O \rightarrow H_2 + ½O_2$

reverse water gas shift

$CO_2 + H_2 \rightarrow CO + H_2O$

water & CO_2 co-electrolysis

$H_2O + CO_2$

$\downarrow$

$CO + H_2 + O_2$

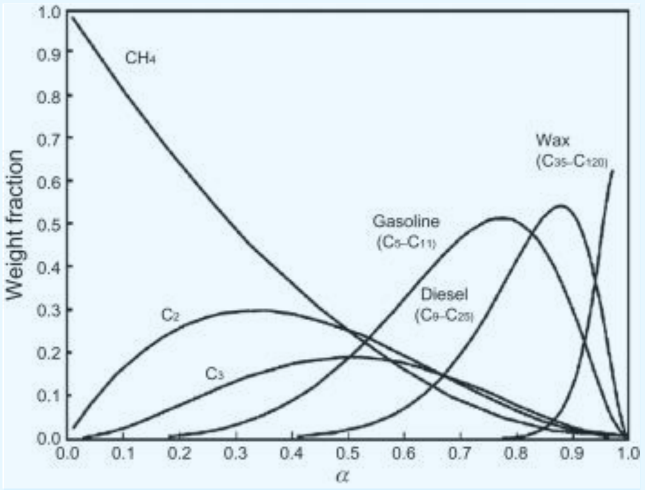
Higher hydrocarbon production

Fischer-Tropsch synthesis

$n CO + (2n+1)H_2$

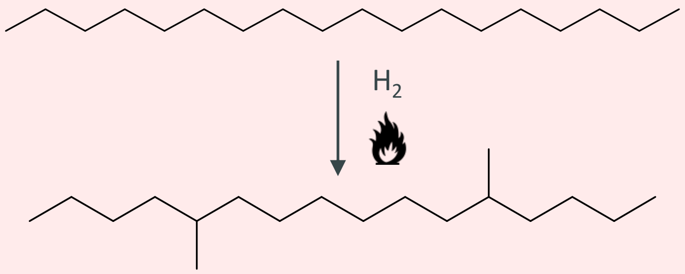
$\downarrow$

$C_nH_{2n+2} + nH_2O$

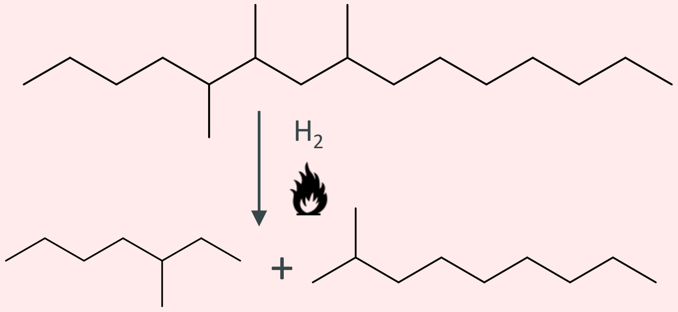


Fuel production

hydroisomerization



hydrocracking



e-Fuel plants of today and tomorrow

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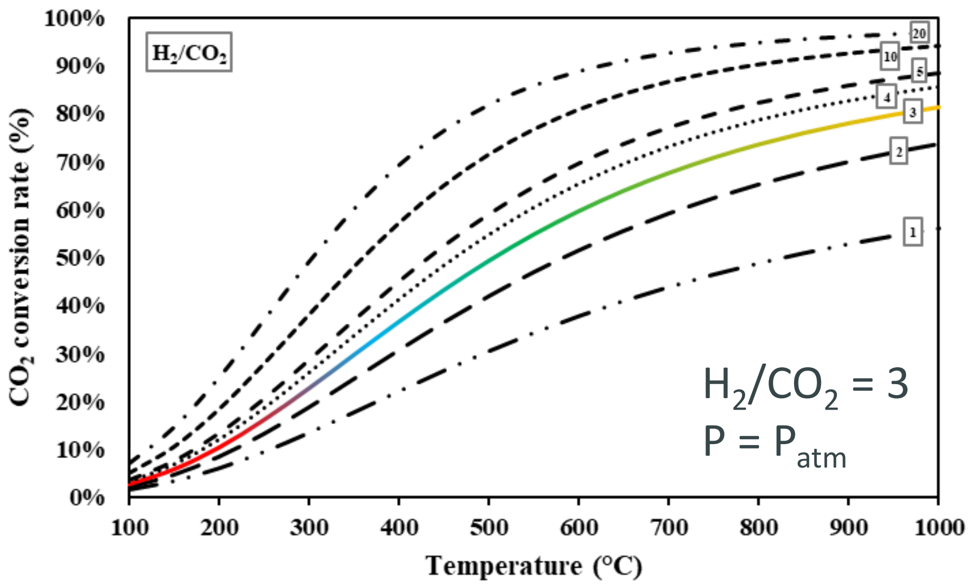
From e-fuel-alliance.eu website

e-fuels from rWGS+FTS	
Reuze CO_2 CIRCULAR ECONOMY	100 kt/y 2025
norsk e-fuel	12.5 Ml/y 2024
Arcadia eFuels	100 Ml/y 2025
Nordic Electrofuel	4.4 Ml/y 2025
Synhelion	0.5 Ml/y 2025
Next GATE INERATEC	INFINIUM Bilbao Decarbonization Hub

Main challenge: reverse water gas shift

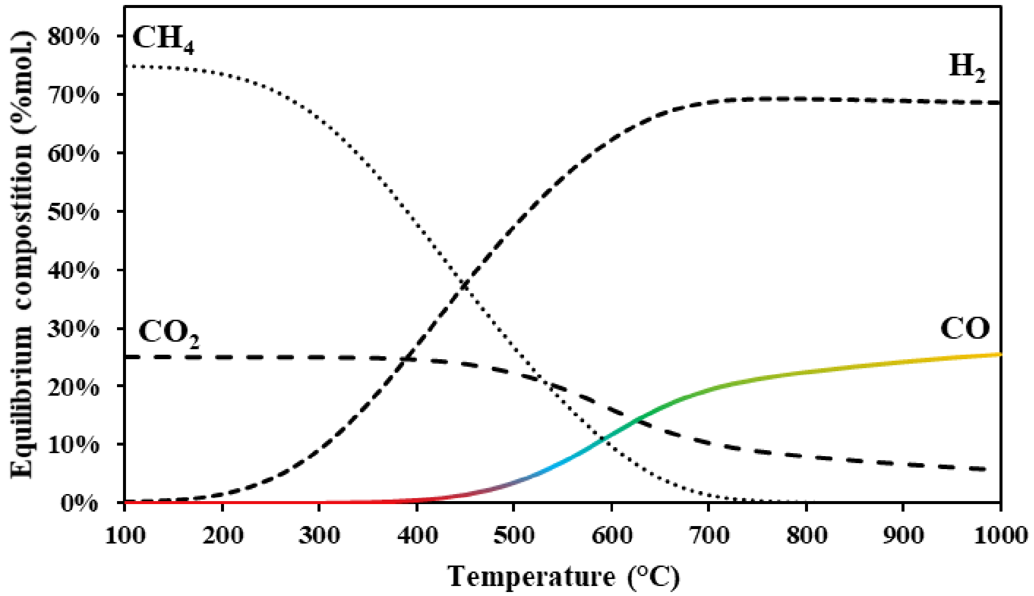
$$CO_2 + H_2 \leftrightarrow CO + H_2O,\ \Delta H_{298K} = +41\ kJ.mol^{-1}$$

1. Thermodynamically limited



X_{CO2}***(400°C) = 37%*** X_{CO2}***(800°C) = 74%***

2. Methane formation favored

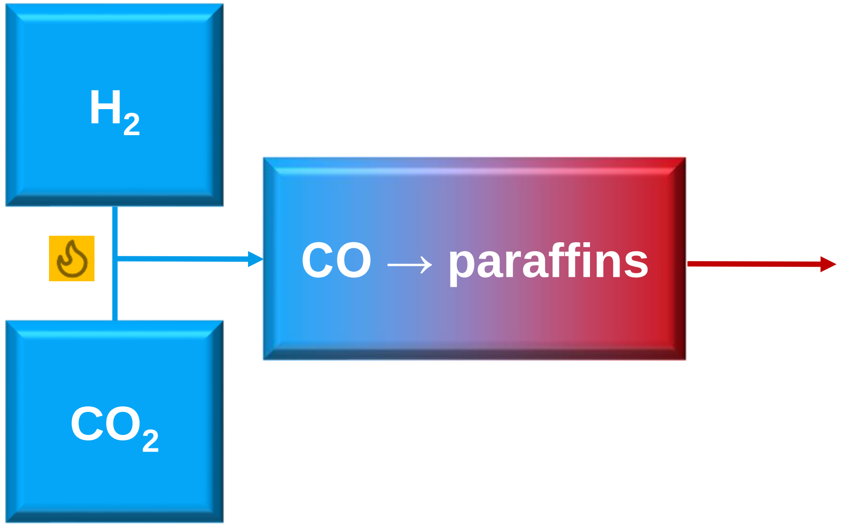


T > 600°C → *rWGS > methanation*

STRATEGY 1 – High temperature operation (> 700 °C), push CO_2 conversion **→ current/future (demo)plants**

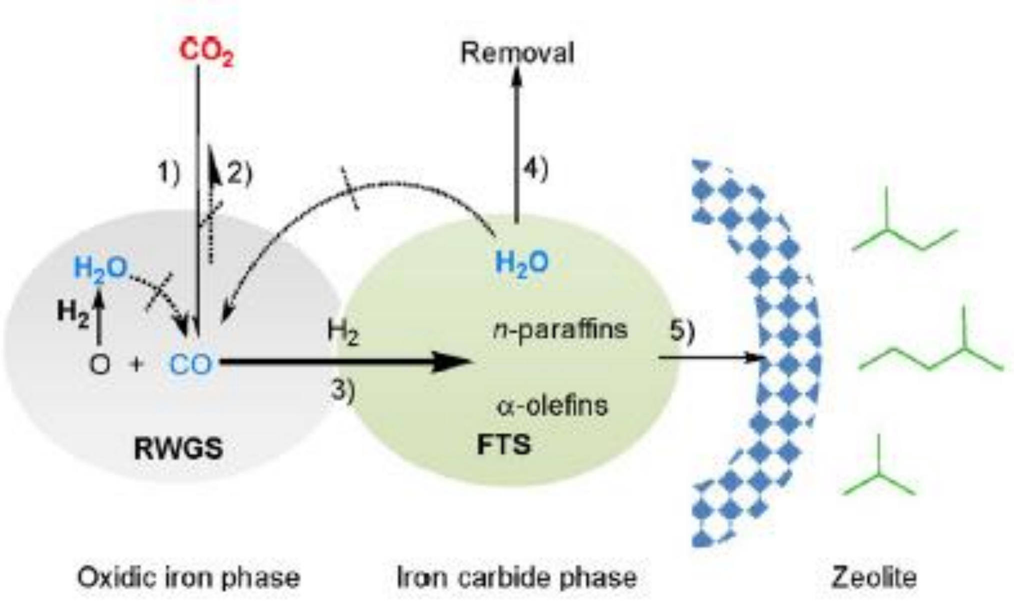
STRATEGY 2 – Low temperature operation (< 500 °C), block pathway to CH_4 **→ academic research**

Single-step production : a feasible alternative?



- \+ Less capital intensive
- \+ Tackle thermodynamic constraints
- – Low TRL 3
- – Process run at suboptimal conditions for rWGS and FTS
- – Smaller paraffins formed

iron-based catalysis



Geng et al. – ChemCatChem 2016

state-of-art performances:

X_{CO2} ~ 35-40 % S_{C5+} ~ 60-65 %

Techno-economic & Life cycle analysis

TEA

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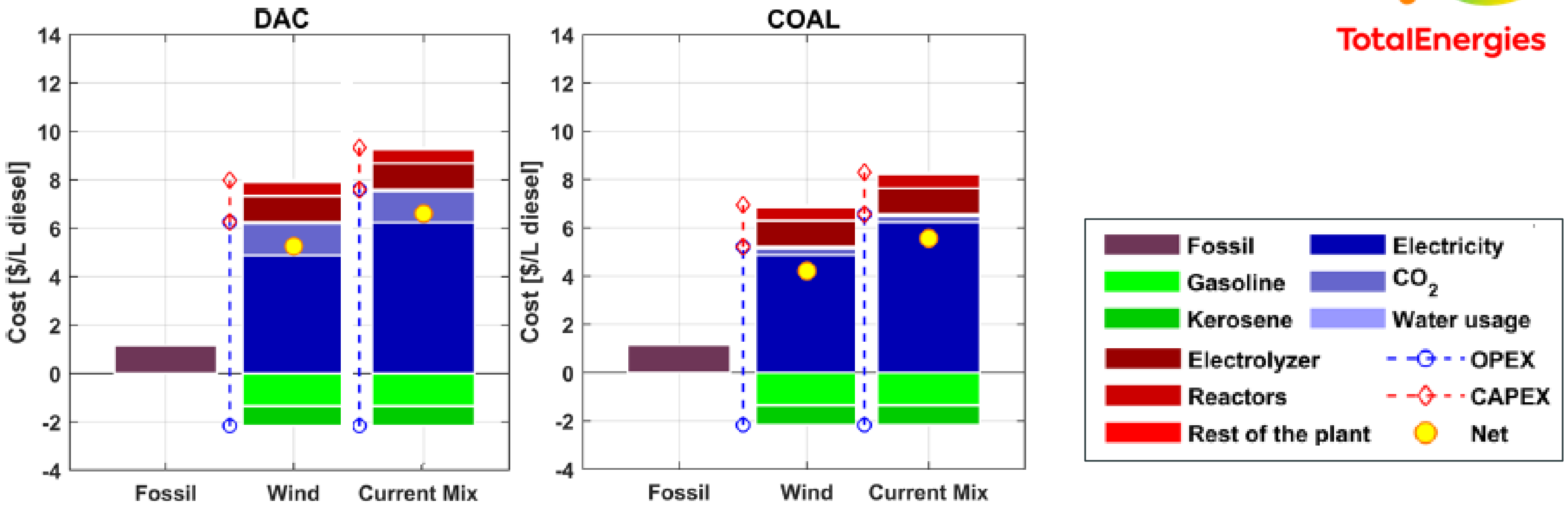
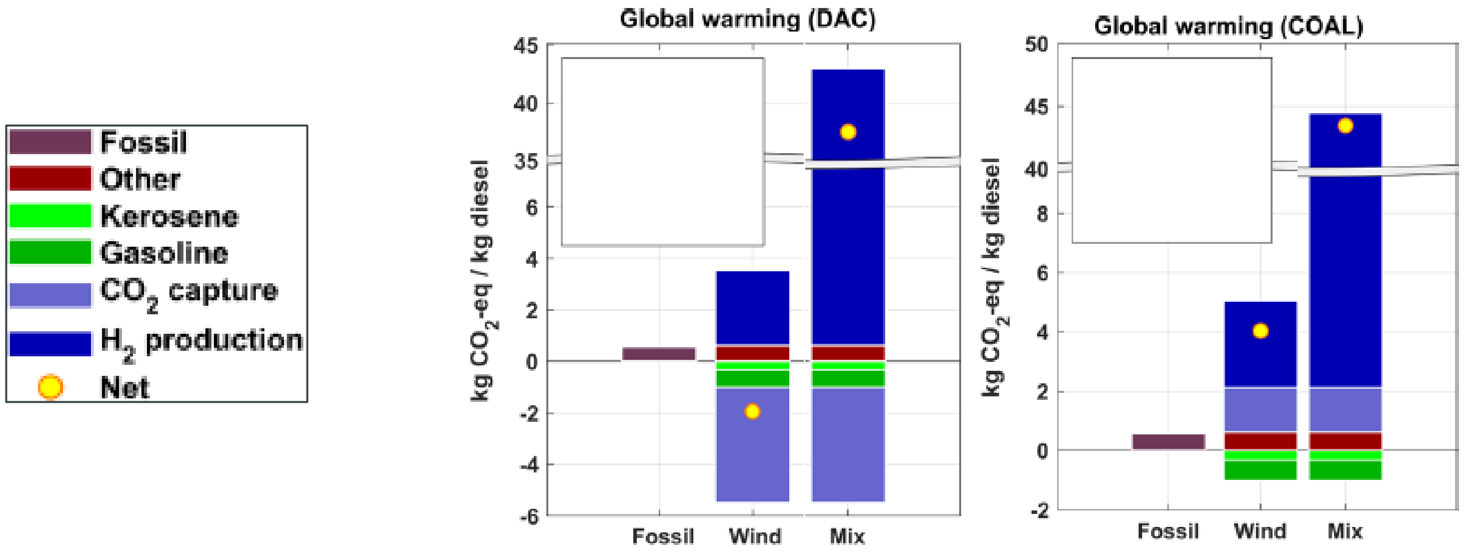
FT e-fuels will be (much) more expensive at start

- ✓ electricity price
- ✓ carbon tax





LCA

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FT e-fuels do not always mitigate climate change

- ✓ electricity source
- ✓ CO_2 source

Medrano-Garcia – ACS Sust Chem Eng 2022

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