CAPHENIA

Turning CO_2 into fuel

Power-and-Biogas-to-Liquid
Power-and-Gas-to-Liquid

PBtL / PGtL

7. Central European Biomass Conference 2023

Kay Kratky, Chair of Caphenia Adv. Board

10 years R&D

Private Investment > 10 mio EUR

First Plant start Construction Components Q2 2023

A unique, new technology route for synthesis gas production:

Power-and-Biogas-to-Liquid	**PBtL**
Power-and-Gas-to-Liquid	**PGtL**

CAPHENIA : One Technology. Two Applications.

Option 1: genetically green. Option 2: almost unlimited feedstock.

Plasma-Boudouard-Reactor

PBtL

Power-and-**Biogas**-to-Liquid

- Electricity
- Methane, CO_2 — **Biogas**
- Water

up to **92%*** CO_2-reduction

The advantages

- ✓ Uses biogas as the entire material flow
- ✓ Reduces the need for renewable electricity
- ✓ Reduces manufacturing costs
- ✓ Produces fuel with an extremely low CO_2 footprint
- ✓ Process scalable

*TUHH (Technical University Hamburg-Harburg) Life Cycle Analysis

PGtL

Power-and-**Gas**-to-Liquid

- Electricity
- Natural gas
- CO_2 ← Point source ← Cement industry / Steel industry
- Water

25-92%* CO_2-reduction

The advantages

- ✓ Uses large local CO_2 emitters
- ✓ Recycles CO_2
- ✓ Results in a CO_2 -free cement and steel industry
- ✓ Produces fuel with reduced CO_2 footprint
- ✓ Has enormous quantity potential due to natural gas

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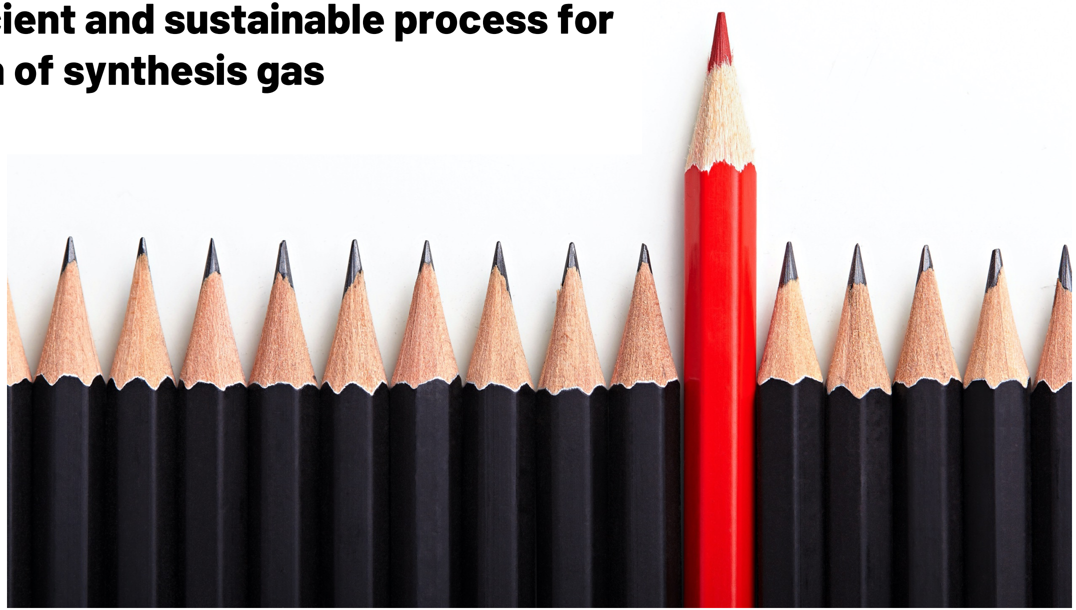
The Task: Convert Methane & CO_2 to Syn Gas to Fuels

The Core Component: Caphenia's Plasma Boudouard Reactor (PBR)

A unique, efficient and sustainable process for the production of synthesis gas (Syngas)



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Three well-known chemical reactions, which have never been combined before

The CAPHENIA process: A unique, new route for the production of variable synthesis gas

$CH_4 \longrightarrow C + 2\,H_2$	Methane pyrolysis	(1)	
$C + CO_2 \longrightarrow CO + CO$	Boudouard reaction	(2)	
$C + H_2O \longrightarrow CO + H_2$	het. Water-Gas-Shift reaction	(3)	

net

from	$3\,CH_4 + 3\,CO_2 \longrightarrow 6\,CO + 6\,H_2$	(1 : 1)	
via	$3\,CH_4 + 1\,CO_2 + 2\,H_2O \longrightarrow 4\,CO + 8\,H_2$	(1 : 2)	FT-synthesis, MeOH-synthesis
to	$3\,CH_4 + 3\,H_2O \longrightarrow 3\,CO + 9\,H_2$	(1 : 3)	

Educt
Product
C Intermediate

Platform Technology

Variably adjustable syngas ratio, by means of variably adjustable ratio of the educt supply. This makes it possible to operate various subsequent synthesis steps. CAPHENIA's platform technology is suitable for the production of fuels and basic chemicals.

Optimum Case refering to a biogas structure CH4/CO2 by 70-75/25-30%

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Biogas Plants and CAPHENIA’s Technology

Most of the existing biogas plants can be upgraded – new ones optimized

Scalable reactor design

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The Caphenia Route: One Technology fits All

Decentral medium - to semi central and central large

The Caphenia Technology will meet various biogas and nat gas plant sizes and corresponding syn crude production volumes from

500t/y to **100.000t/y** to > **1.000.000t/y**

< reactor size ⟶ > < numbering up >

Sustainable.

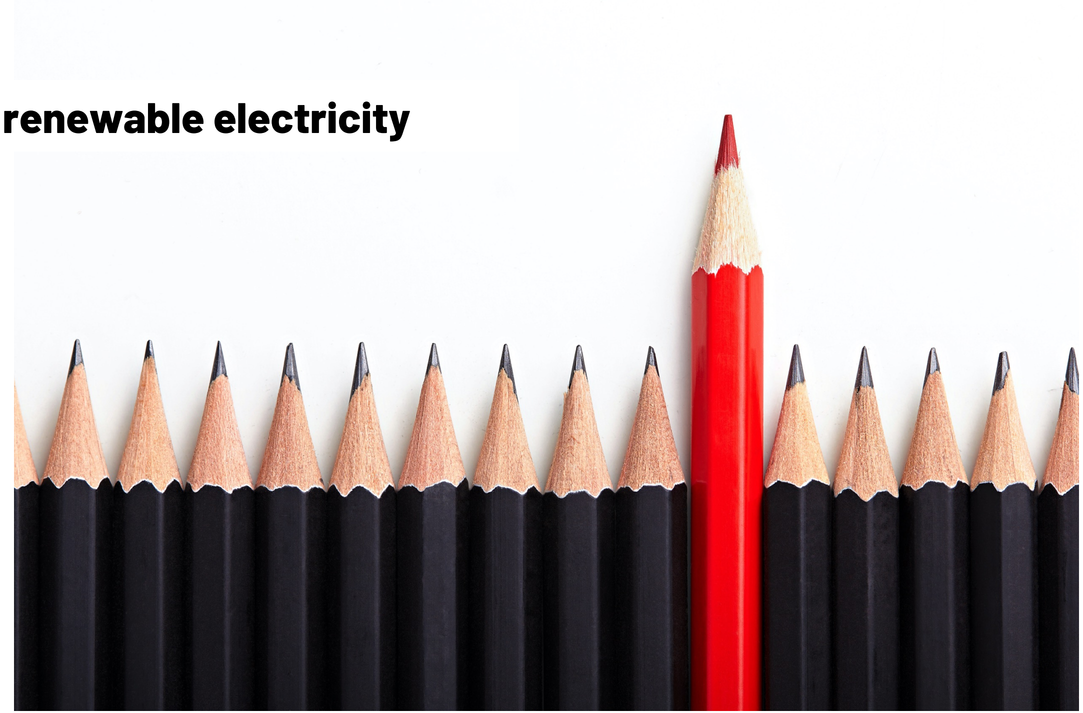
Affordable.

Scalable.

What does CAPHENIA's PBtL/PGtL do better than e-fuel processes?

A real competive edge

Significantly less demand of renewable electricity



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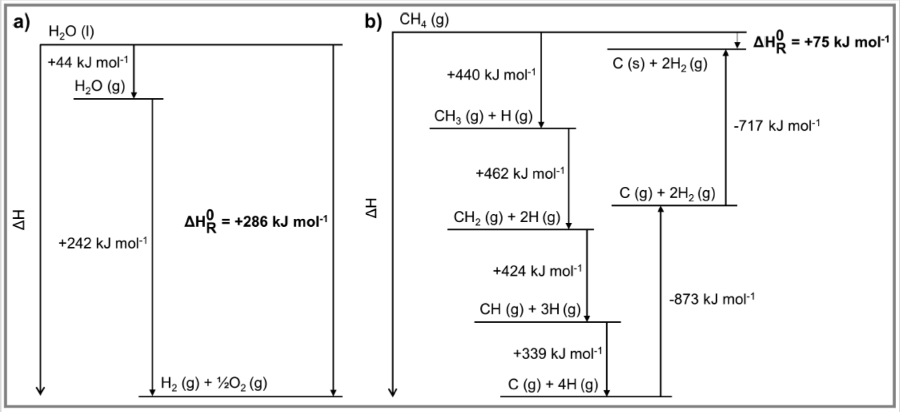
The extraction of H_2 from methane is highly energy-efficient

Methane pyrolysis represents a valuable alternative to water electrolysis



(1) Sanchez-Bastardo, N., Schlögl, R. & Ruland, H. (2020). Methane Pyrolysis for CO2-Free H2 Production: A Green Process to Overcome Renewable Energies Unsteadiness. Chemie Ingenieur Technik. https://doi.org/10.1002/cite.202000029

The Core Technology: The Plasma Boudouard Reactor

First kind of its art

One zone reactor
No Catalysts
3-dimensional Process

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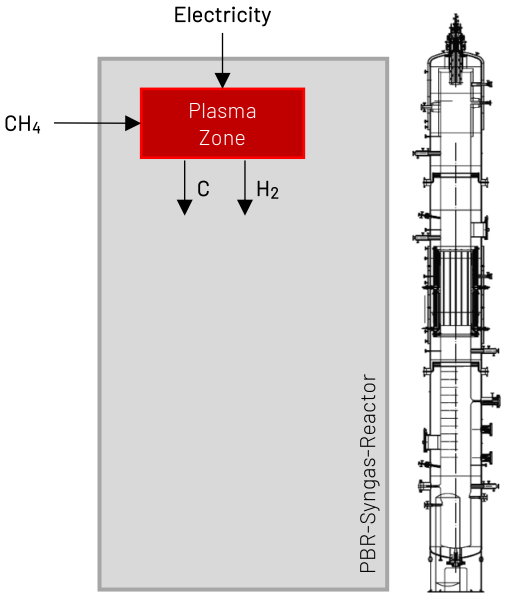
CAPHENIA uses methane pyrolysis for H_2 production

Three quarters of the hydrogen in the novel synthesis gas process results from the pyrolysis of methane

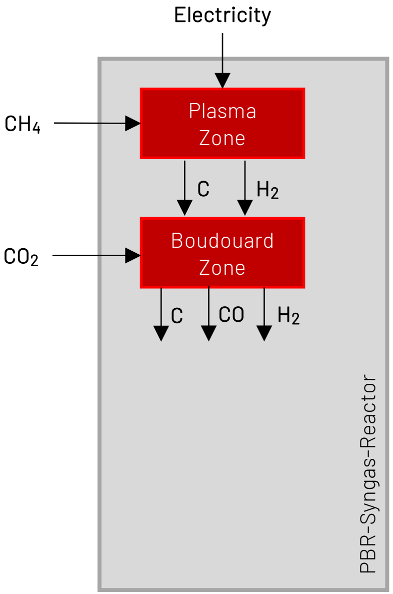


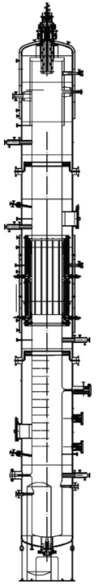
$$CH_4 \longrightarrow C + 2\,H_2$$ Methane pyrolysis (1)

A thermal process of methane pyrolysis is used.
A plasma arc technology allows the efficient injection of thermal energy and a conversion rate >98%.

CAPHENIA combines methane pyrolysis with Boudouard

Thereby disadvantages of the individual processes are transformed into an overall systemic advantage





$CH_4 \longrightarrow C + 2\,H_2$	Methane pyrolysis	(1)
$C + CO_2 \longrightarrow CO + CO$	Boudouard reaction	(2)

The Boudouard reaction can only be accessed via high temperatures.

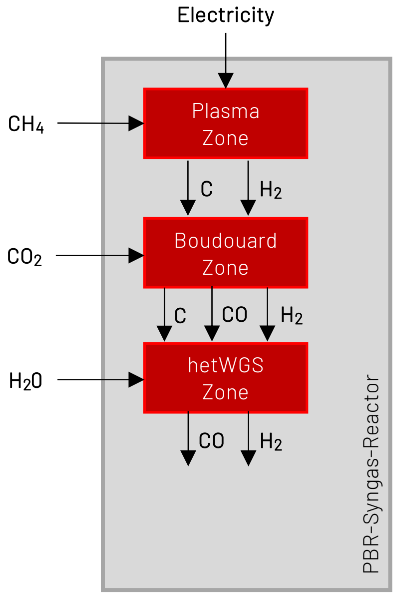
This theoretical disadvantage is transformed into an advantage- through the combination of methane pyrolysis and Boudouard reaction.

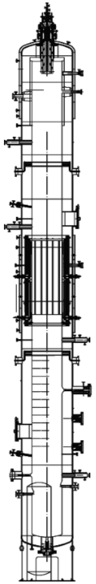
The remaining high thermal energy of the carbon-hydrogen aerosol after pyrolysis can be converted into chemical bonding energy by the Boudouard reaction.

This results in an energetically highly efficient process.

CAPHENIA combines hetWGS and creates a novel flexible syngas process

The CO:H_2 ratio inside the synthesis gas is adjustable





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net

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to	$3\,CH_4 + 3\,H_2O$	$\longrightarrow 3\,CO + 9\,H_2$	(1 : 3)

The het. water gas shift reaction allows the exact adjustment of the molecule ratio between CO and H2. For the purpose of a Fischer Tropsch Synthesis (> fuels and chem. Bulk) and a Methane Synthesis (Mathane > fuels and chem. bulk) a 1:2 ratio is required

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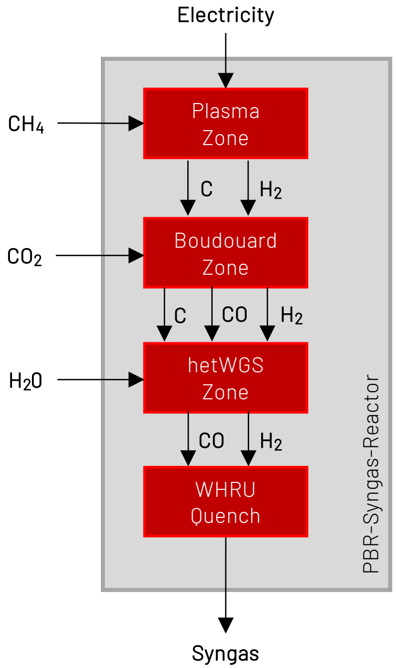
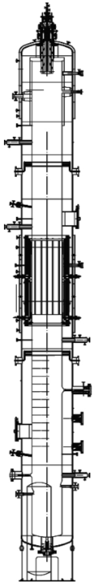
Heat recovery makes the CAPHENIA-process additionally efficient

Quench prevents back reactions





86%

Overall efficiency

Heat recovery

After passing through the hetWGS-stage, the synthesis gas still has a temperature of approx. 900°C. This thermal energy is recovered via heat exchangers and used to preheat the feedstock gases (CH_4, CO_2 und H_2O). Thus the overall process achieves an efficiency[(1)] of 86%.

Quench

The last process step includes a so-called quench. Here the synthesis gas is cooled down in a short time window in order to quickly transit the temperature range in which back reactions (e.g. methanation) can take place. This rapid cooling prevents the back reactions.

PBR-Syngas Reactor

All process steps take place in a single reactor in different zones.

hetWGS	heterogene Wasser-Gas-Shift
PBR	Plasma-Boudouard-Reactor

(1) Efficiency is defined by the ratio of energy output (thermal, chemical) to energy input (electrical, thermal, chemical)

CAPHENIA's PBR* Technology based on Biomass/Biogas

There is no better match

A Bioenergy Circular Economy

circulate products and materials at their highest value

* Plasma Boudouard Reactor

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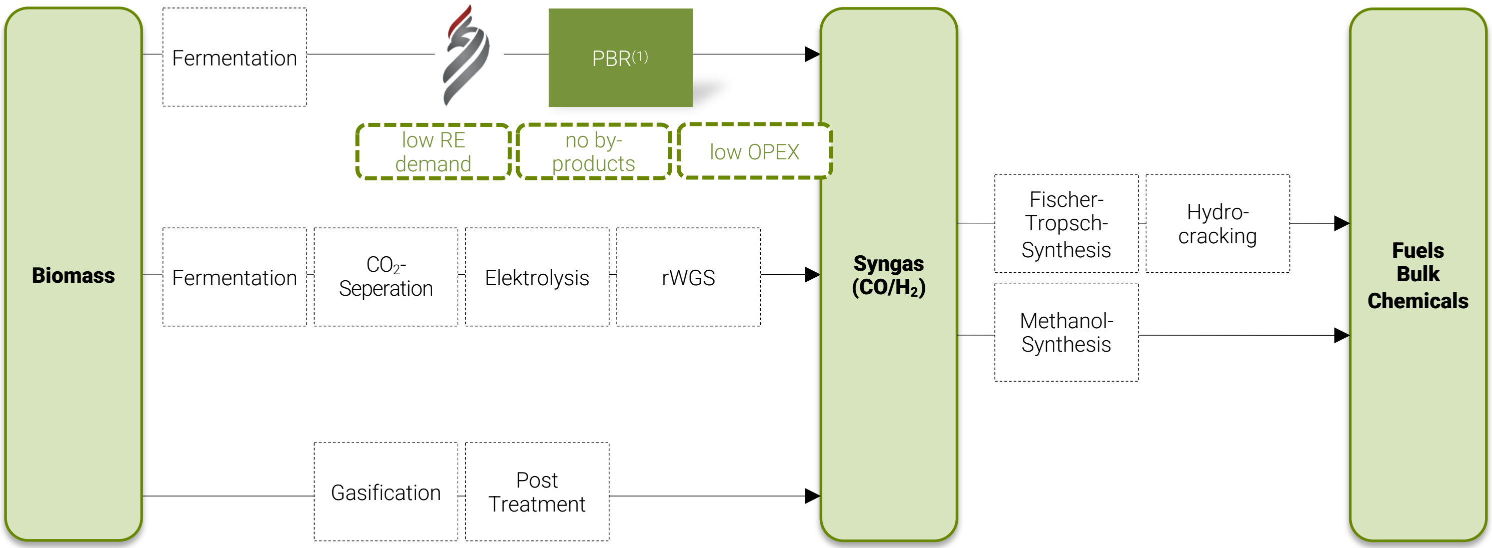
Main Routes from Biomass to Syn Gas to Fuel/Chem Bulk

Classification of the Power-and-Biogas-to-Liquid-Route



(1) Plasma-Boudouard-Reaktor

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Caphenia offers a competitive Package

Maturing markets will decide

Pathway	HEFA	Alcohol-to-jet	Gasification/ Fischer-Tropsch	Power-to-liquid
Cost drivers	Price of feedstock accounts for majority of production cost and is market-driven based on scarceness of feedstock Cost of (green) H_2 presents the biggest opportunity for HEFA production cost improvement	Refining ethanol into jet fuel presents biggest cost bucket Both steps (ethanol production and jet production) are capex-intensive with decline potential in refining due to learning effects	Gasification-FT production cost is largely driven by capital cost	Costs for both RWGS and SOEC routes are highly driven by cost of electricity either for hydrogen production or co-electrolysis Both PtL routes are also capex-intensive and dependent on price of sustainable CO_2
Cost reduction constraints	Limited supply of feedstock and high hurdles for expanding feedstock base to purposely grown oil energy plants constrains feedstock cost reduction	Opex of refining step likely remains relatively high Ethanol production capex already realized learning rate effects, resulting in relatively little additional potential	Capex to build gasifier remains high even after an expected strong decline between 2025 and 2030	Despite steep decline, cost of green electricity remains substantial Capex for FT+RWGS and FT+SOEC have only limited reduction potential

Clean Skies for Tomorrow: Sustainable Aviation Fuels as a Pathway to Net-Zero Aviation

Solution : CAPHENIA

Wide biogenic feedstock base
Besides fats and oils, additional so-called advanced biomasses can be used: urban waste, agricultural waste. Sewage sludge, etc.

Mega natural gas feedstock base
CO2 reduction 25-92*%, billion tons production possible

Power-and-Biomass-to-Liquid (PBtL)

Moderate production cost
no by-products

up to 92%* CO_2-reduction

Power-and-(nat) Gas-to-Liquid (PGtL)

Low production cost

25-92%* CO_2-reduction

Low demand for RE electricity
3.9 MWh/t (1)

High up scaling potential
3-dim. Turbulent gas phase process
No catalyst necessary

*TUHH (Technical University Hamburg-Harburg) Life Cycle Analysis

(1) CAPHENIA (2020). Own calculations based on MAN Engineering

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CAPHENIA's Power & Biogas to Liquid Process

The Highlights – Executive Summary

CAPHENIA

- ✓ Process is realised in a single zone reactor (IP)
  → less complex, thus lower CAPEX costs
- ✓ Process does not release CO_2 intrinsically
  →genetically climate friendly
- ✓ No by-products in general (100% selectivity)
  → no material losses, less energy losses
  > high efficiency
- ✓ No catalysts are needed (for methane synthesis)
  → Longer service life, lower cost (OPEX & CAPEX)
- ✓ 6-times less demand for electricity compared to conventional PtL process
  → Bottleneck resource renewable power is conserved and used most efficiently
- ✓ Easily scalable through pressure increase and 3-dimensional reaction
  → Technology suitable for large industrial scales

Sustainable.

Affordable.

Scalable.

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Outlook : CO_2 negative Hydrogene

Based on same Caphenia core technology

Since the World will not become CO2 neutral in all sectors –
We need to become CO2 negative wherever we can!

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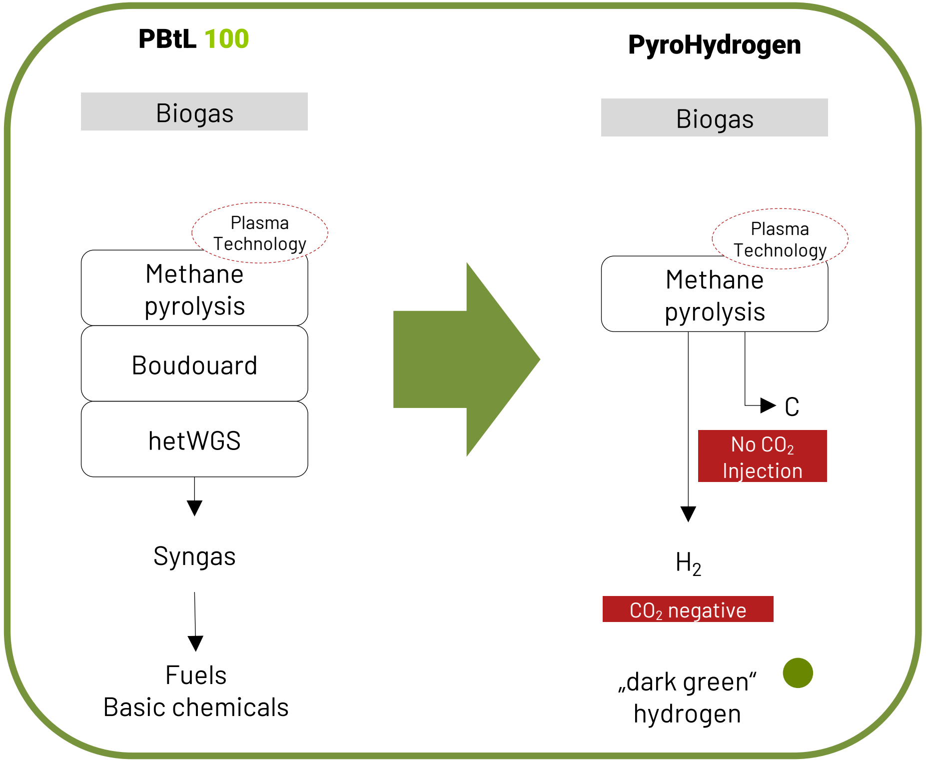
One more Option for decarbonising transport and industry

CAPHENIA develops key technology based on own IP for **CO_2 NEGATIVE H_2** production



ERACRON

- **100% subsidary of Caphenia**
- **CO2 negative H2 production**
- **will become operative 2025ff**

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The Know How Difference

Competition yes – but not based on the same technology

Caphenia is the sole owner of its Intellectual Property

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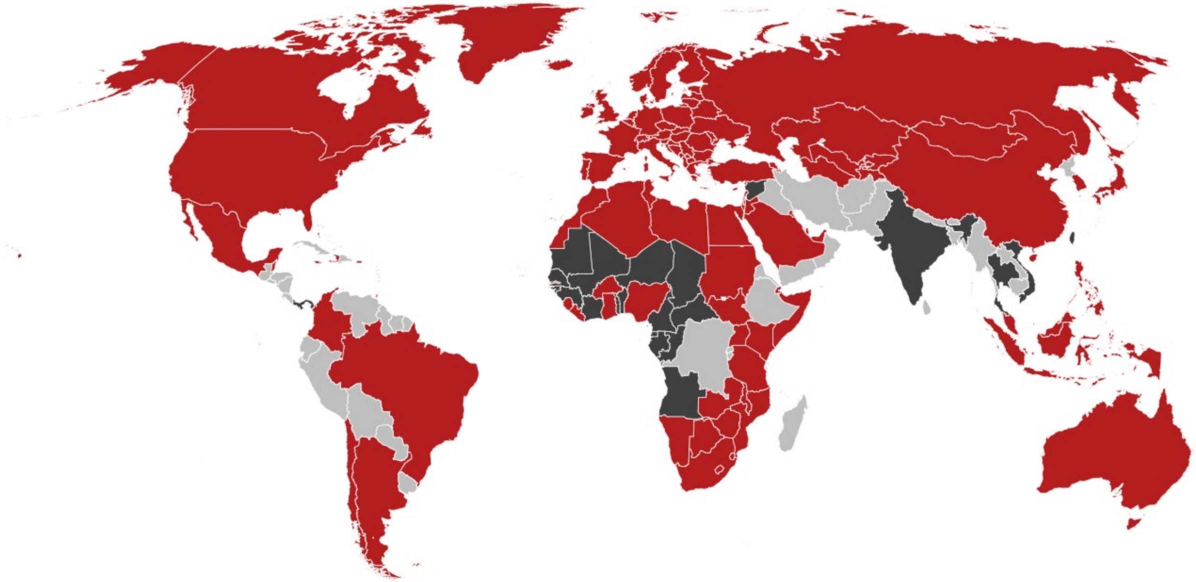
Global IP protection

The CAPHENIA process is patent protected in all relevant global markets



230 total patents

169 granted

61 in progress

Country with at least granted core patent

Country with at least one patent application

Country without application or patents

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2023: A first of its kind plant will be build

Pilot plant will be upgraded to demonstrator size until 2026

Pilot Plant at Industry Park Infraserve, Frankfurt/Germany

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The current development partnerships

CAPHENIA orchestrates a strong team

CAPHENIA
Turning CO_2 into fuel

DLR
Reaction kinetics
Aerosol measurement technology
Numerical simulation

MAN Energy Solutions
Reactor and plant engineering

Hochschule Bonn-Rhein-Sieg University of Applied Sciences
Life Cycle Assessment

J+G REFRACTORIES
Refractory lining

Leibniz-Institut für Plasmaforschung und Technologie
INP FROM IDEA TO PROTOTYPE
Electrical Engineering (Concept)
Plasma experiments

MAX-PLANCK-INSTITUT FÜR CHEMIE
Reaction kinetics
Numerical simulation
Aerosol measurement technology

NM Teknokonsult
Mechanical Engineering (Plasma process)

infranova Biogas – von Infraserv Höchst und Mainova
Co-Fermentation
Biogas plant

TRESCH + KIELIGER ENGINEERING
Mechanical Engineering (Concept, Basic, Detail)

MM-Ingenieure
CFD calculations

infraserv höchst
Site operator

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Location of the Caphenia pilot plant: Frankfurt – Germany

Start construction of components Q2 2023 – Start operation Q1 2025

The commercialization strategy

Rapid market entry. Expansion of the product portfolio. Global rollout through technology licensing.

Proof of Technology ✓ (2022)	Series A (Pilot plant) (2025)	Series B (Commercialization & Tech diversification) (2028)	Series C (Global Scaling)
Funding: > 10 m EUR ✓	26 m EUR	80 - 100 m EUR	Depending on growth rate

Technology Development
- Technical proof of individual processes
- Basic and detail engineering reactor finalized

Pilot plant
- Operation of world's first PBtL plant
- Production of renewable fuels
- Expansion of IP base
- Final "Proof of Technology"

CAPHENIA plant operation, local
- Technical upscaling
- Implementation of fast-follower projects
- Positive turnover from fuel sales
- Business development H_2 route
- Business development CAPHENIA Steel

Technology licensing
- Development of global partner network
- International expansion of organization

Global rollout
- Focus on licensing of technology
- Teaming up for growth strategy
- CAPHENIA supplies turn-key ready reactor

Sustainable
Affordable
Scalable

CAPHENIA
Turning CO_2 into fuel

Thank you!

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