GRAFORCE

TECHNO-ECONOMIC ANALYSIS (TEA) – SYNGAS
20 MW ELECTRICITY-DRIVEN PLASMA SYNGAS PLANT

(All numbers refer to continuous operation at 8 400 h yr-¹, renewable-electricity PPA @ 70 € MWh-¹ and methane @ 35 € MWh-¹)

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1 Purpose & Process & Vision

This TEA evaluates a 20 MW modular plasma plant that produces low-carbon (potentially carbon-negative) syngas—H_2 + CO—from methane and captured CO_2.
By replacing steam-methane reforming (SMR) and coal gasification, the concept targets a > **90 % cradle-to-gate GHG reduction** while remaining cost-competitive.

Process Overview

The plant produces syngas (H_2 and CO) and solid carbon via methane plasmalysis using Graforce's 500-kW modules, Key processes include:

- **Syngas Plasmalysis**: Converts a 50:50 molar mixture of methane (CH_4) and CO_2 into syngas (2CO + $2H_2$) at 1,500 °C plasma temperature, with reactor exhaust at 1,200 °C, consuming 17 kWh/kg H_2 (adjusted for volumetric units).
- **H_2 Plasmalysis**: Converts methane into H_2 and solid carbon (C + $2H_2$) at 8 kWh/Nm³ H_2.
- **CO_2 Source**: CO_2 is captured from refinery off-gases within the same facility, provided by the refinery at no cost (capture and provision heat not included in OPEX).
- **CO_2 and CH4 Preheating**: Preheats CH4 & CO_2 between 400 and 900 °C using waste heat from plasmalysis modules, requiring 1.308 kWh/h.
- **Waste Heat Utilization**: 3 kWh/Nm³ H_2 at 1,200 °C (total 3,232.5 kWh/h) used exclusively for CH4 an CO_2 preheating, with 1,924.5 kWh/h
- **Power Supply**: Electricity via PPA at 0.07 €/kWh, 8,400 h/year, no PV required.

Plant Configuration

Item	Value	Comment
Installed power	**40 × 0.5 MW = 20 MW**	Modular skids
Operating time	**8 400 h a^{-1}**	96 % availability
Module split	10 × H_2-modules 30 × Syngas-modules	
Key reaction (syngas modules)	$CH_4 + CO_2 \rightarrow 2\,H_2 + 2\,CO$	3.978 kg CH_4 + 10.915 kg CO_2 → 1 kg H_2 + 14 kg CO

Item	Value	Comment
Specific electricity	H_2-module 12 kWh kg^{-1} H_2 Syngas-module 17 kWh kg^{-1} H_2-eq	8 kWh plasma + 4 kWh auxiliaries in H_2-line
Energy inputs	**All electricity** via 100 % renewable PPA @ 70 € MWh^{-1}	

3 Material & Energy Balance

Stream	Per hour	Per year
H_2 (total)	1 507 kg h^{-1}	12 659 t a^{-1}
CO (syngas line)	12 351 kg h^{-1}	103 748 t a^{-1}
Turquoise carbon	1 875 kg h^{-1}	15 750 t a^{-1}
Methane feed	6 009 kg h^{-1}	50 474 t a^{-1}
Captured CO_2 feed	9 627 kg h^{-1}	80 868 t a^{-1}
Electricity	22 494 kWh h^{-1}	188 950 MWh a^{-1}

4 Capital Expenditure (CAPEX)

Item	Investment
Plasma modules (40 × 0.5 MW)	50.0 M€
Infrastructure (transformer, foundations, carbon handling, etc.)	5.2 M€
Total CAPEX	**55.2 M€**
Annualised CAPEX (8 % WACC, 20 y)	5.62 M€ a^{-1}

5 Operating Expenditure (OPEX)

Cost item	Calculation	€ a^{-1}
Methane	50 474 t a^{-1} × 13.89 MWh t^{-1} × 35 € MWh^{-1}	**24.53 M€**
Electricity	188 950 MWh a^{-1} × 70 € MWh^{-1}	**13.23 M€**
Labour	5 FTE × 50 k€	**0.25 M€**
Total OPEX		**38.01 M€**

6 Levelised Cost of Syngas (LCOS) for the complete 40-module plant

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(30 Dry-Reforming Modules + 10 Methane-Pyrolysis Modules → $H_2 : CO \approx 1.7 : 1$)

Step	Calculation	Result
1. Annual syngas mass	**H_2:** 625 kg h⁻¹ (pyrolysis) + 882 kg h⁻¹ (dry-reforming) = **1 507 kg h⁻¹** → 12 659 t a⁻¹ **CO:** 12 351 kg h⁻¹ (only dry-reforming) → 103 748 t a⁻¹	**H_2 + CO = 13 858 kg h⁻¹ ⇒ 116 407 t a⁻¹**
2. Annualised CAPEX	Total investment 55.2 M €; CRF(8 %,20 y) = 0.10185	**5.62 M € a⁻¹**
3. Annual OPEX	Methane 24.53 M € + Electricity 13.23 M € + Labour 0.25 M €	**38.01 M € a⁻¹**
4. Total annual cost	5.62 + 38.01	**43.63 M € a⁻¹**
5. LCOS	43.63 M € a⁻¹ ÷ 116 407 t a⁻¹	**≈ 0.38 € kg⁻¹ syngas**

Impact of Selling Turquoise Carbon at 500 €/t

(30 syngas-modules + 10 methane-pyrolysis modules; 15 750 t a⁻¹ solid carbon available)

Item	Baseline (no C-credit)	With 500 €/t carbon credit
Annual cost (CAPEX + OPEX)	43.63 M € a⁻¹	43.63 M € − (15 750 t × 500 €/t) = **35.76 M € a⁻¹**
Annual syngas mass	116 407 t a⁻¹	116 407 t a⁻¹ (unchanged)
LCOS (€/kg syngas)	43.63 M € / 116 407 t = **0.38 €/kg**	35.76 M € / 116 407 t = ≈ **0.31 €/kg**

Levelised Cost of Syngas (LCOS) – 30 Syngas Modules

- Syngas output 882 kg H_2 h⁻¹ + 12 351 kg CO h⁻¹ = **111 157 t a⁻¹**
- Syngas-related CAPEX share ≈ 41.4 M€ → annual charge 4.22 M€
- Syngas-OPEX methane 14.34 M€ + electricity 8.82 M€ + labour 0.19 M€ = 23.35 M€

- **LCOS_syngas** (4.22 + 23.35) M€ / 111 157 000 kg = **0.25 € kg-¹**

Levelised Cost of Hydrogen (LCOH) – 10 Methane-Pyrolysis Modules

- **H_2 output** 625 kg H_2 h^{-1} = **5 250 t a^{-1}**
- **Carbon by-product** 1 875 kg h^{-1} = 15 750 t a^{-1}
- **Pyrolysis-related CAPEX share** 10 × 1.25 M€ + 25 % of infrastructure
  = **13.8 M€** → annual capital charge **1.41 M€ a^{-1}**
- **Pyrolysis-OPEX**
  – methane 21 000 t a^{-1} × 13.89 MWh t^{-1} × 35 € MWh^{-1} = **10.2 M€**
  – electricity 63 000 MWh a^{-1} × 70 € MWh^{-1} = **4.41 M€**
  – labour (25 %) = **0.06 M€**
  → **Total OPEX = 14.68 M€ a^{-1}**

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7 Economic Performance (Whole Plant)

Metric	Value
Revenue	H_2 (12 659 t × 2 €) + CO (103 748 t × 0.15 €) + Carbon (15 750 t × 0.5 €) = **48.8 M€ a^{-1}** *(assumes 500 € t^{-1} carbon black)*
Annual cost	CAPEX 5.62 M€ + OPEX 38.01 M€ = **43.63 M€ a^{-1}**
Net cash flow	**+5.1 M€ a^{-1}**
IRR (20 y)	**≈ 9 %**
NPV (8 %)	**≈ 15 M€**
Simple payback	**~11 years**

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8 Life-Cycle Assessment (LCA)

- **Cradle-to-gate GHG intensity** 10–15 g CO_2-eq MJ^{-1} syngas (SMR ≈ 90–100 g).
- Key drivers
  – Renewable electricity (zero scope-2).
  – Direct utilisation of captured CO_2 (no new fossil carbon).
  – 15 750 t a^{-1} solid carbon stores ≈ 58 000 t CO_2-eq yr^{-1}.
- **Net result** Baseline is carbon-neutral; carbon-negative if the solid carbon is land-filled or locked in long-lived products.

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9 Benchmark versus Conventional Routes

Route	Levelised Cost (H_2-eq)	GHG Intensity
Coal gasification	≈ 1.4 € kg^{-1}	≈ 12 kg CO_2 kg^{-1} H_2
SMR (natural gas)	≈ 1.2 € kg^{-1}	≈ 9 kg CO_2 kg^{-1} H_2
Plasma syngas	**≈ 0.25 € kg^{-1}**	**≈ 0.6 kg CO_2 kg^{-1} H_2 (gross)**

With ETS pricing > 80 € t^{-1} CO_2, the plasma route is both **cheaper and > 90 % cleaner**.

10 Conclusions & Next Steps

1. **Economically viable replacement** for SMR/gasification where low-carbon power and modest carbon pricing are available.
2. Profitability hinges on **selling turquoise carbon** or obtaining **CO_2 credits**.
3. **Optimise heat integration** and consider downstream e-fuel (FT, methanol) coupling to boost value.

Graforce replaces conventional, carbon-intensive molecules with net-CO_2-negative alternatives — provided that renewable energy and carbon valorization are incorporated.

What does “net CO_2 negative” mean in this context?

An alternative is *net CO_2 negative* if its total greenhouse gas balance (life cycle assessment, cradle-to-grave) is less than zero. This means that

The total amount of CO_2 equivalents released during raw material extraction, process operation, product use, and end-of-life is less than the amount that is permanently bound or avoided through substitution of conventional processes.

System boundaries and mass balance equation

$$\text{Net CO}_2 = \underbrace{\text{process-related emissions}}_{\text{e.g. electricity, auxiliaries}} + \underbrace{\text{upstream emissions}}_{\text{extraction, transport}} - \underbrace{\text{permanently bound carbon}}_{\text{solid C from plasmalysis}} - \underbrace{\text{substitution credits}}_{\text{avoided SMR / coal gasification, carbon black, etc.}}$$

Net CO_2 < 0 ⇒ CO_2-negative

How does methane plasmalysis achieve a net-negative CO_2 balance?

Building block	Impact on the balance
Renewable electricity (PV/Wind PPA)	Drives process-related emissions close to zero; grid electricity with a higher carbon intensity would worsen the balance.
Solid carbon (turquoise carbon)	Permanently binds the carbon contained in methane. A credit is granted as long as the carbon is not re-oxidised (e.g., landfilling or incorporation into long-life products).
Substitution credit for H_2 / syngas	Every tonne of H_2 or syngas from plasmalysis displaces H_2 or CO produced via SMR or coal gasification, thereby avoiding their emissions.
Additional substitution (carbon black, petcoke, CaC_2-acetylene)	Generates extra credit when turquoise carbon or acetylene replaces fossil, CO_2-intensive products.

Example figures (syngas case, per 1 kg product)

Contribution	CO_2-equivalent*
Process electricity (38 g CO_2 / kWh, ≈ 3 kWh/kg)	**+0.11 kg**
Upstream CH_4 leakage (0.5 %)	**+0.05 kg**
Subtotal "gross emissions"	**+0.16 kg**
Solid carbon sequestered	**–0.27 kg**
Avoided SMR-H_2 (equivalent)	**–1.02 kg**
Net balance	**–1.13 kg CO_2-eq**

* simplified example; source: internal LCA

Result: **–1.13 kg CO_2-eq → net CO_2-negative**.

Critical conditions

1. **Electricity source**
   If the power mix exceeds ~200 g CO_2 / kWh, the balance shifts toward carbon-neutral or even positive.
2. **Fate of the carbon**
   Only permanently sequestered or materially utilised carbon earns a credit. If it is combusted later, the negative effect disappears.
3. **System boundaries & methodology**
   Substitution credits must be assigned consistently and transparently (ISO 14044, PEF Guidance, etc.).