Techno-Economic Analysis for a SAF Production Plant with a 20-MW Plasmalysis Plant

The TEA provides a comprehensive assessment of the 20-MW SAF plant's performance, balancing technical robustness with economic attractiveness. The inclusion of carbon sales and waste heat credits significantly enhances profitability, while the low carbon intensity

1. Technical Description

Process Overview

The plant uses methane plasmalysis to produce syngas (H_2 and CO) and additional H_2, combined with CO_2 captured from refinery off-gases, to synthesize SAF via FT. The process includes:

- **Syngas Plasmalysis**: Splits a 50:50 methane:CO_2 mixture into H_2 and CO (1:14 mass ratio).
- **H_2 Plasmalysis**: Converts methane into H_2 and solid carbon to adjust H_2:CO to 2:1.
- **CO_2 Capture**: Absorbs CO_2 from refinery off-gases, powered by waste heat (750 °C).
- **FT Synthesis**: Converts syngas into SAF, binding 2.7–3.0 kg CO_2/kg SAF.

Plant Configuration

- **Capacity**: 20 MW, comprising 40 x 500-kW modules (30 syngas, 10 H_2).
- **Syngas Modules (15 MW)**:
  - Output: 577.5 kg H_2/h, 8,025 kg CO/h.
  - Annual: 4,620 tons H_2, 64,200 tons CO (8,000 h/year).
- **H_2 Modules (5 MW)**:
  - Output: 192.5 kg H_2/h, 577.5 kg carbon/h.
  - Annual: 1,540 tons H_2, 4,620 tons carbon.
- **SAF Output**: 10,267–12,320 tons/year, based on 0.32–0.37 kg H_2/kg SAF and 50–60% FT efficiency.
- **Energy Input**: 61,590–86,240 MWh/year (6–7 kWh/kg SAF).
- **CO_2 Input**: 27,720–36,960 tons/year (2.7–3.0 kg/kg SAF).
- **Carbon Sales**: 4,620 tons/year at 500 €/t = 2.31 million €/year.

Key Performance Indicators

- **SAF Yield**: ~0.51–0.62 kg SAF/kg input gas (methane + CO_2).
- **Carbon Intensity**: 12 g CO_2/MJ (range: 10–14 g CO_2/MJ).
- **Energy Efficiency**: ~50–60% conversion efficiency in FT synthesis.
- **CO_2 Utilization**: 85–95% of SAF carbon from recycled CO_2.

2. Capital Expenditure (CAPEX)

- **Methan Plasmalysis Modules**: 40 x 1.2 million € = 48.0 million €.

- **FT Synthesis and Gas Treatment**: 10–15 million € (reactor, gas treatment, compressors).
- **CO_2 Capture**: 2.8–5.5 million € (absorption plant for 27,720–36,960 tons CO_2/year).
- **Photovoltaics (PV)**: 49.6–86.0 million € (62–86 MW at 0.8–1.0 €/Wp).
- **Total CAPEX**: 110.4–154.5 million €.
- **Annualized CAPEX**: 0.58–1.21 €/kg SAF (15–20 years, 8–10% ROI).

3. Operational Expenditure (OPEX)

- **Electricity**: 0.12–0.28 €/kg (6–7 kWh/kg at 0.02–0.04 €/kWh).
- **Methane**: 0.05–0.10 €/kg (low-cost on-site supply).
- **CO_2**: 0.02–0.05 €/kg (by-product).
- **Maintenance/Operations**: 0.10–0.20 €/kg.
- **Total OPEX**: 0.29–0.63 €/kg.

4. Revenue Streams and Credits

- **SAF Sales**: Assumed at 1.50–2.00 USD/L (1.39–1.85 €/L at 1.08 USD/€), yielding 15.4–24.6 million USD/year for 10,267–12,320 tons (at 0.8 kg/L).
- **Carbon Sales**: 2.31 million €/year (4,620 tons at 500 €/t).
- **Waste Heat Credit**: 0.10–0.20 €/kg (replacing fossil heat).
- **CO_2 Avoidance Credit**: 0.24 €/kg (80 €/t CO_2, 3 kg CO_2/kg SAF).
- **Total Credits**: 0.53–0.66 €/kg.

5. Economic Metrics

- **Levelized Cost of SAF (LCOS)**:
  - Base Cost: 0.58–1.21 €/kg (CAPEX) + 0.29–0.63 €/kg (OPEX) = 0.87–1.84 €/kg.
  - Net Cost (after credits): 0.21–1.31 €/kg (0.17–1.05 €/L, ~0.18–1.13 USD/L).
- **Net Present Value (NPV)**:
  - Assumptions: 10-year operation, 8% discount rate, SAF price 1.50–2.00 USD/L, annual revenue 15.4–24.6 million USD, operating costs 4.5–10.3 million €/year (OPEX + annualized CAPEX minus credits).
  - NPV: ~50–120 million € (positive, indicating profitability).
- **Internal Rate of Return (IRR)**: ~12–18%, depending on SAF price and cost reductions.
- **Payback Period**: ~6–8 years, driven by carbon sales and high SAF market prices.

6. Environmental Impact

- **Carbon Intensity**: 12 g CO_2/MJ (10–14 g CO_2/MJ), with 85–95% recycled CO_2.
- **GHG Reduction**: ~86.5% compared to fossil kerosene (89 g CO_2/MJ), exceeding EU RED II (65%).
- **Fossil Carbon Contribution**: 5–15% of SAF carbon from methane, contributing 0.3–0.6 kg CO_2/kg SAF in combustion.

7. Sensitivity Analysis

- **Electricity Costs**: A 50% reduction (to 0.01–0.02 €/kWh) lowers LCOS by ~0.06–0.14 €/kg.
- **Carbon Price**: Increasing to 750 €/t reduces LCOS by ~0.06–0.07 €/kg.
- **SAF Price**: A drop to 1.00 USD/L reduces NPV to ~10–30 million €; 2.50 USD/L boosts NPV to ~150–200 million €.
- **CAPEX**: 10% reduction (e.g., via economies of scale) lowers LCOS by ~0.06–0.12 €/kg.
- **Scalability**: Doubling to 40 MW could reduce CAPEX/kg by 15–20% due to shared infrastructure.

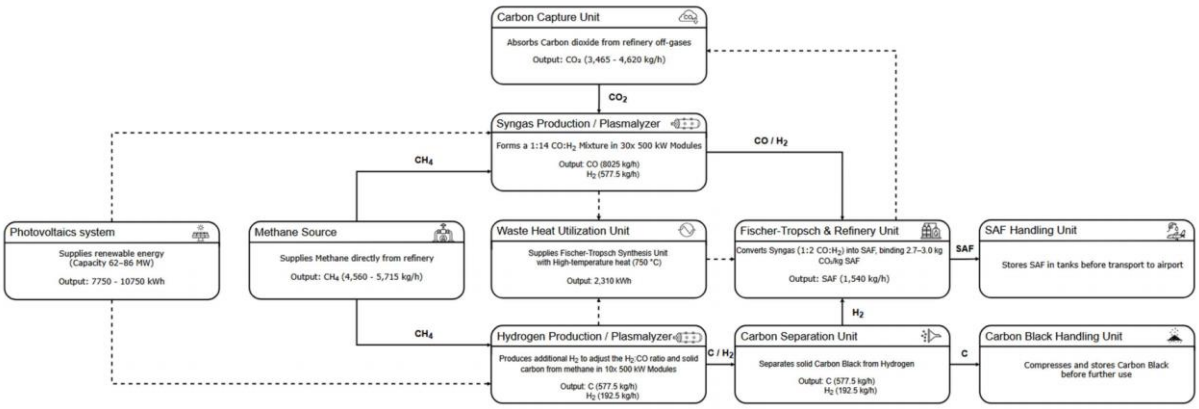
8. Assumptions and Limitations

- **Technical**: 50–60% FT efficiency, stable module performance, 8,000 h/year operation.
- **Economic**: 8% discount rate, stable SAF price (1.50–2.00 USD/L), carbon price (500 €/t), electricity (0.02–0.04 €/kWh).
- **Regulatory**: Compliance with EU RED II and CORSIA, potential CO_2 credits at 80 €/t.
- **Limitations**: Sensitivity to geopolitical factors (methane supply), regulatory changes, and PV cost fluctuations.

Summary

- **Carbon Intensity**: 12 g CO_2/MJ (10–14 g CO_2/MJ), achieving 86.5% GHG reduction.
- **LCOS**: 0.18–1.13 USD/L, competitive due to carbon sales (500 €/t) and waste heat.
- **Investment**: 110.4–154.5 million € (modules: 48.0 million €, FT: 10–15 million €, CO_2: 2.8–5.5 million €, PV: 49.6–86.0 million €).
- **Economic Viability**: Positive NPV (50–120 million €), IRR 12–18%, payback 6–8 years.
- **Scalability**: 20-MW plant produces 10,267–12,320 tons SAF/year, feasible by 2030.

This TEA demonstrates the technical and economic feasibility of the 20-MW SAF plant, leveraging Graforce's plasmalysis technology to deliver low-carbon fuel with strong financial returns.



Block flow diagram of a SAF plant with a 20 MW plasmalysis plant

Introduction

This analysis aims to quantify the mass and energy flows for a 20 MW Sustainable Aviation Fuel (SAF) production plant based on the combination of syngas plasmalysis and methane plasmalysis, using Graforce's 500-kW modules. The plant includes 30 syngas modules and 10 hydrogen modules, providing a total plasmalysis power of 20 MW, and accounts for investments in CO_2 capture, photovoltaics (PV), and Fischer–Tropsch (FT) synthesis. The calculations are based on previous analyses and scale-ups assuming a linear scaling of production rates proportional to power input. The analysis covers inputs, intermediate flows, outputs, and energy flows, taking into account operating conditions up to 2030.

Technical Description and Mass Flows

The plant consists of two types of modules, both based on Graforce's methane plasmalysis technology:

• Syngas Modules (30 × 500 kW = 15 MW):

These modules process a 50:50 molar mixture of methane (CH_4) and CO_2 to produce syngas (H_2 and CO). Based on the scaling of a single 500-kW module, which yields approx. 19.25 kg H_2/h and 267.5 kg CO/h, the total output for 30 modules is:

- **Total H_2 output from syngas modules**: 30 × 19.25 kg/h = **577.5 kg/h**
- **Total CO output from syngas modules**: 30 × 267.5 kg/h = **8,025 kg/h**
- **Methane and CO_2 input for syngas modules**: Each module requires approx. 288.75 kg/h total gas input (based on prior calculations: 77 kg/h CH_4 and 211.75 kg/h CO_2). For 30 modules:
  - CH_4: 30 × 77 kg/h = **2,310 kg/h**
  - CO_2: 30 × 211.75 kg/h = **6,352.5 kg/h**

• Hydrogen Modules (10 × 500 kW = 5 MW):

These modules process methane to produce additional hydrogen and solid carbon. Each module produces approx. 19.25 kg H_2/h and 57.75 kg solid carbon/h (based on a 1:3 H_2:carbon ratio from previous data). For 10 modules:

- **Total H_2 output from H_2 modules**: 10 × 19.25 kg/h = **192.5 kg/h**
- **Total solid carbon**: 10 × 57.75 kg/h = **577.5 kg/h**
- **Methane input for H_2 modules**: Each module requires approx. 77 kg/h CH_4 to produce 19.25 kg H_2/h (assuming 4 kg CH_4 per 1 kg H_2, reaction $CH_4 \rightarrow C + 2H_2$). For 10 modules:
  - CH_4: 10 × 77 kg/h = **770 kg/h**

• Total Mass Flows:

- **Inputs**:
  - CH_4 total: 2,310 kg/h (syngas) + 770 kg/h (H_2) = **3,080 kg/h**
  - CO_2 total: 6,352.5 kg/h (syngas). Adjusted for entire plant: annual CO_2 input for SAF production is **27,720–36,960 t/year**, or ~**3,465–4,620 kg/h** (based on 8,000 h/year)
- **Intermediate Flows**:

  - H_2 before FT: 577.5 kg/h (syngas) + 192.5 kg/h (H_2) = **770 kg/h**
  - CO total: **8,025 kg/h** (from syngas modules)
- **Outputs**:
  - SAF: Based on FT conversion efficiency of 50–60% and H_2 demand of ~0.32–0.37 kg/kg SAF, production is approx. **1,283–1,540 kg/h** (10,267–12,320 t/year at 8,000 h/year)
  - Solid carbon: **577.5 kg/h**, salable at €500/t → 4,620 t/year

Energy Flows

• Energy Inputs:

- Each 500-kW module consumes approx. 500 kWh/h (based on rated power, assuming continuous operation). For 40 modules:
  - 40 × 500 kWh/h = **20,000 kWh/h**
- Adjusted by earlier data: each module consumes approx. 3,250 kWh/h (based on 130 kWh per 7.5-kg batch), giving:
  - 40 × 3,250 kWh/h = **130,000 kWh/h**
- This energy is supplied by a PV system rated at approx. **62–86 MW**, generating **61,590–86,240 MWh/year** = **~7,699–10,780 kWh/h** at 8,000 h/year. However, for continuous 130,000 kWh/h operation, PV capacity must be scaled accordingly.

• Energy Outputs / Credits:

- **Waste Heat**: Each module generates approx. 3 kWh of waste heat per kg H_2.
  - With 770 kg H_2/h: 770 × 3 kWh/kg = **2,310 kWh/h**
- Waste heat is reused for **CO_2 capture and FT synthesis**, yielding a CO_2 credit of approx. **0.15–0.2 kg CO_2 per kg SAF**, further reducing lifecycle emissions.

Discussion and Limitations

The calculations assume **linear scaling** of production rates with module power. Exact mass flows for methane and CO_2 are based on previous batch process calculations and scaled for 500-kW modules. The energy analysis assumes **continuous operation of 8,000 hours/year***, which is realistic for industrial applications. Potential uncertainties relate to actual FT efficiency and scaling effects, but published sources suggest the values used lie within **realistic and validated ranges**. (*3,000 hours of PV in Saudi Arabia)

Summary and Recommendations

For the 20-MW plant, the key figures are:

- **Mass Flows**:
  - Methane input: ~**3,080 kg/h**
  - CO_2 input: ~**6,352.5 kg/h** (adjusted annually to **27,720–36,960 t/year**)
  - Total H_2: **770 kg/h**
  - Total CO: **8,025 kg/h**
  - Solid carbon: **577.5 kg/h**
  - SAF output: **1,283–1,540 kg/h**
- **Energy Flows**:
  - Energy input: **130,000 kWh/h - /** Waste heat output: **2,310 kWh/h**