4-PLATFORM (ISOBUTENE, C5-STREAM, LIGNIN, VINASSE) BIOREFINERY PLANT USING WOODY RESIDUES FOR THE PRODUCTION OF SUSTAINABLE AVIATION FUEL, LIGNIN-BLEND ASPHALT, ETBE, FERTILIZER, PROCESS STEAM AND ELECTRICITY

This case study presents a comprehensive Technical, Economic, and Environmental (TEE) assessment of a **second-generation lignocellulosic biorefinery** that converts residual softwood sawdust into **sustainable aviation fuel (SAF)** via a wood-to-sugars platform, **fermentation to bio-isobutene (IBN)**, and **oligomerization/hydrogenation to isoparaffins**. All results and diagrams presented here are based on **high-level approximations** intended to illustrate the conceptual SAF pathway rather than provide detailed engineering design data.[1] The configuration valorizes multiple co-products—**lignin** (on-site boiler/CHP energy and/or asphalt binder[2]), **C5-sugar-to-ethanol**, **fermentation sludge** (K/Ca fertilizer credit), and **microbial biomass** (animal feed)—consistent with circular-bioeconomy principles. At commercial scale, engineered balances envisage **~415 kt·a^{-1}** dry sawdust input and indicative outputs of **~30.2 kt·a^{-1}** **SAF**, **~165 kt·a^{-1} lignin (dry)**, **~28 kt·a^{-1} ethanol**, **~89.2 kt·a^{-1} fertilizer sludge**, and **~6.8 kt·a^{-1} microbial biomass**; in lignin-CHP layouts, ~105.8 kt·a^{-1} lignin is used energetically to meet process heat demand.

The assessment applies a **cradle-to-gate** boundary and certification-grade accounting (EU **RED II/RED III**[3] energy-based allocation for energy products with **avoided-burden** credits for non-energy co-products; **CORSIA** referenced[4]), with scenarios varying process-energy supply (**natural-gas vs. lignin boiler/CHP**) and electricity mix (**EU-28 vs. high-RES**). Utilities choices dominate results: in the **lignin-CHP + RES** best case, SAF achieves **~6.6 g CO_2-eq/MJ** (≈ 93 % below the 94 g CO_2-eq/MJ RED II comparator); ISO-style scenarios span **~18-56 g CO_2-eq/MJ** depending on utilities and co-product handling.

Economically, the concept is **CAPEX-intensive** (installed cost order-of-magnitude **~€598 M**) with **feedstock** as the second-largest cost block; Using current, conservative EU pricing, a SAF selling price of ~€2,200 t^{-1} at the reference output (~30.2 kt a^{-1}) yields ~€66.4 Mio a^{-1} from SAF alone; including conservative co-product revenues (lignin ~€11.8 M, ethanol ~€14.0 Mio, microbial biomass ~€1.36 Mio, fertilizer sludge ~€0.89 Mio, and modest power export ~€1.0 M) brings total revenues to ~€94-95 Mio a^{-1} against **~€85 Mio a^{-1}** in annual costs—i.e., a modest **~€9-10 Mio a^{-1}** margin that remains sensitive to SAF price realization and co-product offtake.

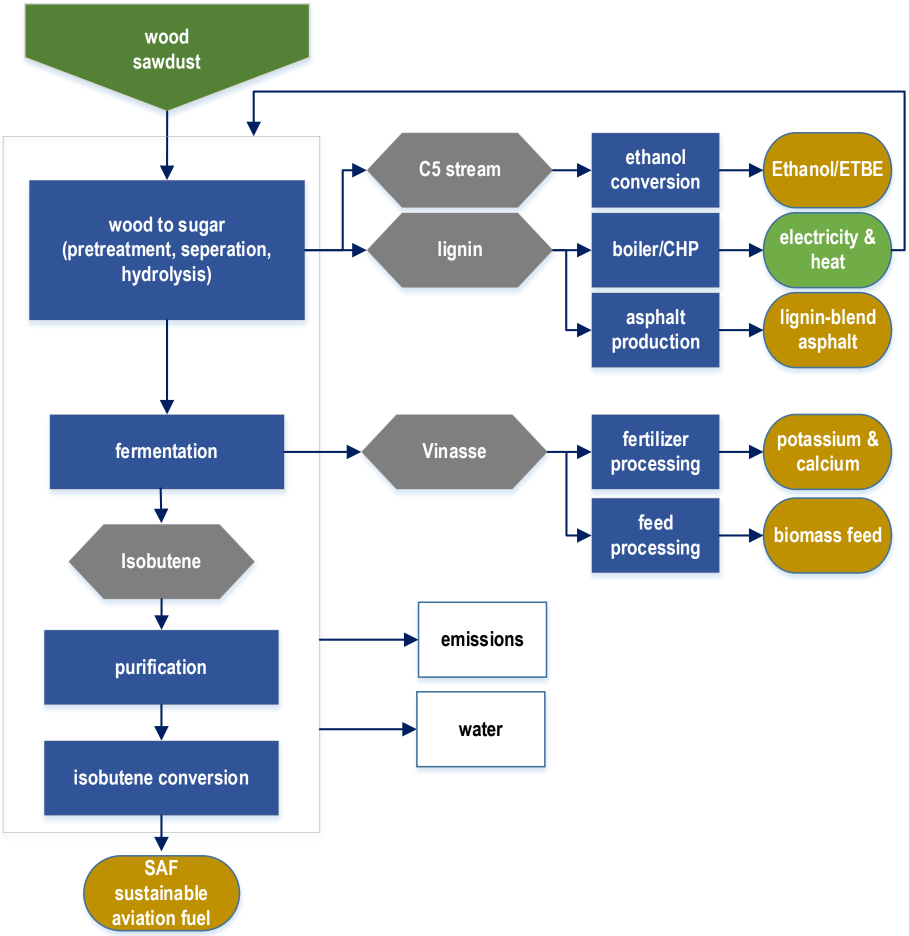
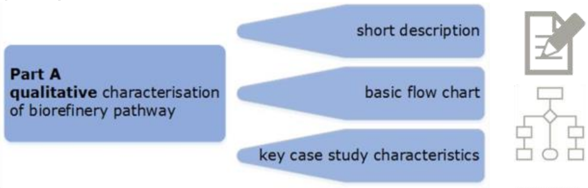


Figure 1: Basic flow chart of the ***second-generation lignocellulosic biorefinery*** *that converts residual softwood sawdust into* ***sustainable aviation fuel (SAF)*** *case study*

1. Introduction

Deep decarbonization of aviation is emerging as a priority within the broader transition of global energy systems. Because long-haul air travel remains hard to electrify, **drop-in sustainable aviation fuels (SAF)** are central to near- and medium-term climate strategies in Europe and beyond.[5] This case study examines an innovative **second-generation (2G) lignocellulosic biorefinery** that converts residual softwood (sawdust) into SAF via a wood-to-sugars platform, fermentation to **bio-isobutene**, and downstream oligomerization/hydrogenation to **isoparaffins** suitable for jet fuel blending. The pathway valorizes multiple by-product streams—**lignin**, **C5 sugars (to ethanol)**, **fermentation sludge (as Ca/K fertilizer)**, and **microbial biomass (as animal feed)**—consistent with circular-bioeconomy principles.



Technologically, the concept integrates proven unit operations into a novel configuration: pretreatment and enzymatic hydrolysis liberate C6/C5 sugars; the C6 fraction is fermented to gaseous isobutene; upgrading yields SAF-range isoparaffins. **Lignin** can be used **on-site** as a process energy carrier (boiler or CHP) and/or **off-site** as a **bitumen substitute**—a design choice that materially affects both energy self-sufficiency and life-cycle performance.

The study applies a **transparent Technical, Economic, and Environmental (TEE)** lens, anchored in **ISO 14040/14044** life-cycle assessment and aligned with **EU RED II** and **CORSIA** certification frameworks. **Energy-based allocation (LHV)** is used to distribute burdens among energy products (SAF, lignin, ethanol), complemented by a **hybrid "avoided-burden" treatment** for non-energy co-products (fertilizer, animal feed). Scenario analysis varies **process energy provision** (fossil vs. lignin boiler/CHP) and **electricity mix** (EU-28 average vs. high-RES), capturing the strong influence of grid intensity on results.

At commercial scale, the engineered balances envisage **~415 kt/y dry sawdust** input, with by-product valorization and on-site auxiliaries sized accordingly. Depending on the final product slate, annual outputs include ~**30 kt SAF** (alternative campaigns can produce ION or ETBE). Logistics favor regional feedstock sourcing to minimize transport burdens.

Headline environmental findings underline the value of **lignin-to-energy integration** and **renewable electricity**: in the **SAF + Lignin-CHP + RES** case, cradle-to-gate emissions reach ~**6.6 gCO_2-eq/MJ**, corresponding to ~**93%** reduction relative to the RED II fossil reference; ISO-based scenario work finds similarly low values when the grid is decarbonized. Across layouts, **SAF pathway emissions** span roughly ~**18-56 gCO_2-eq/MJ**, with the lowest values achieved when **lignin supplies process heat** and **RES covers power demand**.

Beyond climate metrics, **primary energy demand (PED)** and **energetic/exergetic efficiencies** are quantified to locate process bottlenecks and improvement levers. The analysis confirms that **co-product utilization** (especially lignin) is critical to system-level efficiency and that country-specific electricity footprints can dominate comparative results—reinforcing the case for **on-site CHP** and **high-RES power** procurement.

In sum, this SAF case study demonstrates a **scalable, multi-product, residue-based biorefinery** with credible pathways to **>90% GHG reduction** under favorable energy supply assumptions. It provides decision-grade evidence on **design choices (boiler vs. CHP, on- vs. off-site lignin use, grid mix)**, establishes **comparable LCA baselines** under RED II/CORSIA, and surfaces **process-level targets** to accelerate deployment of net-zero-aligned industrial biorefineries in regions rich in underutilized woody residues.

2. Method of assessment for sustainable aviation fuel oriented biorefinery case study

2.1. Current status and development trends of SAF oriented biorefineries

Advanced biorefineries are shifting from single-product concepts to **multi-product value chains** that prioritize drop-in **sustainable aviation fuel (SAF)**[6] while valorizing co-products such as **lignin, C5-sugar-to-ethanol, organic fertilizer (Ca/K credits), and microbial protein**. In this case, residual **softwood sawdust** is deconstructed to C6/C5 sugars, fermented to **bio-isobutene (IBN)**, and upgraded via **oligomerization/hydrogenation to SAF-range isoparaffins.** The route is at **demonstration scale** and is being advanced for **ASTM D7566**[7] annex inclusion; certification analyses follow **EU RED II** and **CORSIA** GHG frameworks.[8]

To situate this pathway among today's SAF options, the table below compares **ASTM-recognized** routes by blend limits and typical feedstocks (indicative). Our pathway ("wood-to-IBN SIP-like isoparaffins") is under consideration and thus shown as **emerging**:

SAF pathway (ASTM name)	Max blend (vol%)	Typical feedstocks / notes
FT-SPK (Annex 1)	50	Lignocellulosic residues via gasification/FT.
HEFA-SPK (Annex 2)	50	Waste lipids/vegetable oils (e.g., UCO).
SIP (Annex 3)	10	Fermented sugars → iso-paraffins (sugar platforms).
ATJ-SPK (Annex 5)	50	Alcohols (ethanol/isobutanol) to jet.
CHJ (Annex 6)	50	Hydrothermolysis of lipids.
Wood-to-IBN isoparaffins (this case)	—*	Residual softwood → sugars → **bio-IBN** → iso-paraffins; in ASTM D7566 evaluation.

*Blend limit to be defined upon ASTM approval.

Market drivers & trends. EU **RefuelEU Aviation** sets indicative SAF blend targets of **5% by 2030, 32% by 2040, 63% by 2050**, catalyzing scale-up across multiple pathways. Cost challenges persist, but **scale effects and co-product valorization** are identified levers for competitiveness.[9]

What differentiates this biorefinery. The concept integrates **on-site energy provision from lignin (boiler/CHP)** and targets a **RES electricity mix**, both of which shift cradle-to-gate GHG from ~56 down to **~18-19 gCO_2e/MJ (ISO)**, and to **~6.6 gCO_2e/MJ (RED II, best-case LI-CHP + RES)** when allocation and credits are applied as specified.

2.2. Key challenges in assessment

Data sparseness at demo scale. Novel steps (e.g., **IBN fermentation yields**, purification energy, and IBN-to-jet upgrading) still rely partly on project data and literature proxies, requiring transparent assumptions in the LCI.

Methodological consistency. ISO 14040/44 prioritizes system expansion; **RED II** mandates **LHV-based energy allocation**; **CORSIA** introduces its own comparator and rules. Reconciling these within one model—and deciding where to apply **credits vs. allocation**—materially affects results.[10]

Boundary and scenario sensitivity. Electricity carbon intensity (EU-28 vs. high-RES 2050), choice of **lignin use** (energy vs. asphalt binder), and **on-site CHP coverage** dominate both **GWP** and **PED** outcomes; consistent scenario design is essential for fair comparison.

Economic realism. CAPEX intensity, feedstock price exposure, and product slate selection (e.g., campaign to **ION** when margins are stronger) remain critical; early analyses show CAPEX and feedstock dominate cost structure at demo scale.

Assessment of biorefinery systems is complicated by:

- Limited availability of high-quality data, especially for low-TRL systems
- Methodological inconsistencies in Life Cycle Assessment (LCA)
- Allocation and system boundary decisions that affect comparability

This study addresses these issues using standardized guidelines:

- ISO 14040 series for LCA methodology[11]
- EU Renewable Energy Directive (RED III) for GHG accounting[12]
- VDI 6310 for classification and economic parameters[13]

2.3. Classification system used

We apply **IEA Bioenergy Task 42**'s poly-hierarchical classification to ensure comparability and modular growth:

- **Feedstock:** Residual softwood sawdust (regional EU supply).
- **Platforms: C6/C5 sugars → bio-isobutene (gaseous)** as the intermediate platform
- **Processes:** Pretreatment & enzymatic hydrolysis → fermentation (bio-IBN) → purification → **oligomerization/hydrogenation** to SAF; **lignin boiler/CHP** and off-site auxiliaries.
- **Products: SAF (main)**; **lignin** (energy/binder), **ethanol (from C5)**, **fertilizer credits (Ca/K)**, **microbial protein (animal feed)**; plus **steam/electricity** from CHP.

This map supports pathway evolution (e.g., shifting lignin between energy/material markets, or alternating SAF/ION/ETBE campaigns) without losing comparability.

2.4. The TEE Assessment Framework

We build on the **TEE** approach (Technical-Economic-Environmental) with a **transparent, Excel-based fact-sheet** on prior work by Lindorfer et al. (2019)[14] and consolidating open literature, engineered balances, and certification-grade calculations.

Technical. Mass/energy balances for a **~415 kt/a (dry) sawdust** input; product campaigns of **~30 kt/a SAF** (alternatively ION or ETBE); on-site energy variants (**NG boiler/CHP** vs **lignin boiler/CHP**), and EU-28 vs **RES** electricity. **KPIs** include unit yields, **PED** (allocated/non-allocated), and energetic/exergetic efficiencies at product and system level.

Economic. High-level indicators (**CAPEX/OPEX**, minimum selling price, revenue split, IRR) reflect demo-scale realities: **CAPEX share ~largest cost block**, feedstock the second, corresponding to a dry sawdust price of roughly **50-55 €/t** in the Baltic context, with sensitivity to product slate (e.g., near-term **ION** margins vs SAF).

Environmental.

- **Standards: ISO 14040/44** LCA as backbone; **RED II** (fossil comparator **94 gCO_2e/MJ**, **LHV energy allocation**); **CORSIA** (comparator **89 gCO_2e/MJ**, ≥10% reduction).
- **Allocation & credits: Energy-based allocation** among energy products (SAF, ethanol, lignin) plus **hybrid avoided-burden credits** for non-energy co-products (fertilizer, animal feed).
- **Scenario findings (headline): LI-CHP + RES** delivers **~6.6 gCO_2e/MJ (RED II)** for SAF (≈**93%** reduction vs 94), while ISO scenario work spans **~18.7-56 gCO_2e/MJ** depending on energy supply and co-product handling.

Model transparency. The fact-sheet compiles feedstock logistics, utilities, and product slates into a **reproducible** structure for benchmarking across sites and years; it also flags the **dominance of electricity carbon intensity** and **lignin routing** on GHG/PED outcomes—guiding design toward **lignin-to-CHP** and **high-RES power**.

3. CASE STUDY ANALYSIS - PART A: BIOREFINERY PLANT

3.1. Overview and System Boundary

This case study examines a **commercial-scale, second-generation (2G) lignocellulosic biorefinery** designed to produce **sustainable aviation fuel (SAF)** from **residual softwood (sawdust)**. The facility—engineered around a **Baltic state** siting concept—converts sawdust to **C6/C5 sugars**, ferments C6 sugars to **bio-isobutene (IBN)**, and upgrades IBN via **oligomerization/hydrogenation** to **SAF-range isoparaffins**. Co-products are deliberately valorized: **lignin** (as on-site energy carrier and/or bitumen substitute), **C5-sugar-to-ethanol**, **fermentation sludge** (K/Ca fertilizer credit), and **microbial biomass** (animal feed credit), consistent with circular-bioeconomy principles.

The assessment applies a **cradle-to-gate** boundary: it includes **feedstock logistics (regional sawdust supply and transport), pretreatment and hydrolysis, fermentation, IBN purification, SAF conversion, utilities (boiler/CHP), and off-site auxiliaries**. Product distribution beyond the plant gate is excluded except where required for scenario-specific logistics accounting in the fact-sheet. **GHG accounting** follows **EU RED II** (energy-based allocation, fossil comparator 94 gCO_2e/MJ) and, for SAF scenarios, **CORSIA**; **ISO 14040/44** scenarios are provided to benchmark methodological sensitivity. Key drivers varied in scenarios are **process-energy provision (natural gas vs. lignin; boiler vs. CHP)** and **electricity mix (EU-28 vs. high-RES)**.

Table 1: Key technical characteristics of the SAF biorefinery case study (fact-sheet basis)

Key parameter	Characteristic
Primary feedstock (dry)	Residual softwood (sawdust), **~415 $kt\cdot a^{-1}$** regional supply concept.
Core platform	Wood-to-sugars (pretreatment + enzymatic hydrolysis) → **bio-isobutene (gaseous)** fermentation → IBN purification → **isoparaffins (SAF)** via oligomerization/hydrogenation.
Main product	**SAF** (isoparaffins), **~30.2 $kt\cdot a^{-1}$** (campaign mode).
Co-products (indicative)	**Lignin ~165 $kt\cdot a^{-1}$ (dry)**; **ethanol ~28 $kt\cdot a^{-1}$** (from C5 sugars); **sludge ~89.2 $kt\cdot a^{-1}$** (fertilizer credit); **microbial biomass ~6.8 $kt\cdot a^{-1}$** (animal-feed credit).
Utilities concept	**Lignin boiler/CHP** covers thermal demand; electricity from CHP and/or grid (EU-28 or high-RES scenarios).
Location concept	**Europe, Baltic States (demo concept)**; regional sawdust logistics emphasized.
Technology status	Demonstration / pre-commercial integration of proven unit ops into novel configuration; ASTM D7566 annex evaluation targeted.
Headline GHG results (SAF)	**RED II, SAF LI-CHP + RES: ~6.6 gCO_2e/MJ** (≈**92.9%** reduction vs. 94). **ISO scenarios: ~18-56 gCO_2e/MJ** depending on energy supply and allocation/credits.

System boundary note. The "off-site (auxiliaries)" system—storage, conveyance, pumps, blowers, heat exchangers, etc.—is explicitly modeled because it materially contributes to utilities and handling burdens at commercial scale.

3.2. Process Description

The process route in this case study follows a **lignocellulosic sugar platform** rather than fast pyrolysis. Residual **softwood sawdust** is deconstructed to **C6/C5 sugars**, the **C6 fraction** is fermented to **gaseous bio-isobutene (IBN)** using engineered *E. coli*, and purified IBN is upgraded via **oligomerization and hydrogenation** to **SAF-range isoparaffins** suitable for blending under ASTM D7566 (annex under evaluation). Along the chain, multiple by-products are valorized: **lignin** (as process energy via boiler/CHP and/or as a **bitumen substitute**), **C5-to-ethanol**, **fermentation sludge** providing **K/Ca fertilizer credits**, and **microbial biomass** as **animal-feed protein**—key levers for both environmental and economic performance.

Process sequence (SAF campaign):

- **Feed handling & deconstruction.** Regional sawdust is received and conditioned; **pretreatment + enzymatic hydrolysis** liberate C6/C5 sugars and separate a **lignin-rich solids** stream. C5 sugars are routed to **ethanol**; lignin is directed either **on-site to boiler/CHP** for process heat/power or **off-site** to substitute asphalt binder, depending on the scenario.

- **Fermentation (bio-IBN).** The **C6 sugar liquor** is fermented with engineered *E. coli* to **gaseous isobutene**; **sludge** (fertilizer K/Ca) and **biomass** (animal-feed protein) arise as co-products. IBN is then **purified** via an adsorption/desorption column system.

- **Conversion to SAF.** Purified IBN is **oligomerized and hydrogenated** to **isoparaffins** in the jet-range. The same conversion train can be campaigned to **ION** or **ETBE** for market flexibility, but **SAF** is the reference product in this study.

- **Utilities & energy integration.** Thermal demand is covered by **natural-gas or lignin boiler**, or by **NG/lignin-CHP**; electricity is supplied by **on-site CHP and/or grid** (EU-28 mix or high-RES scenario). Utilities choices are decisive for cradle-to-gate results.

System design benefits (vs. single-product routes):

Polygeneration with targeted co-product valorization (lignin, ethanol, fertilizer, animal feed) to lift overall energy/exergy performance.

Internal energy self-sufficiency via lignin-to-boiler/CHP, reducing exposure to high-carbon grids; scenarios demonstrate strong sensitivity to the electricity mix.

Certification-aligned accounting. The pathway is modeled for **RED II/CORSIA** using **LHV-based energy allocation** across energy products and **avoided-burden** credits for non-energy co-products—matching the fact-sheet used for TEE results.

Indicative flows at commercial scale (Europe/baltic concept, SAF campaign): ~415 $\mathrm{kt{\cdot}a^{-1}}$ dry sawdust in; outputs **~30.2 $\mathrm{kt{\cdot}a^{-1}}$** SAF, **~165 $\mathrm{kt{\cdot}a^{-1}}$ lignin (dry)**, **~28 $\mathrm{kt{\cdot}a^{-1}}$ ethanol**, **~89.2 $\mathrm{kt{\cdot}a^{-1}}$ fertilizer sludge**, **~6.8 $\mathrm{kt{\cdot}a^{-1}}$ microbial biomass**. In **LI-CHP + RES** layouts, **~105.8 $\mathrm{kt{\cdot}a^{-1}}$ lignin** is used energetically to meet heat demand.

Environmental headline (cradle-to-gate, SAF): With **lignin-CHP** and **RES electricity**, emissions reach **~6.6 $\mathrm{gCO_2}$-eq/MJ (RED II)**—**≈92.9%** below the 94 $\mathrm{gCO_2}$-eq/MJ fossil comparator; ISO scenarios span **~18-56 $\mathrm{gCO_2}$-eq/MJ** depending on utilities and allocation/credits.

3.3. Mass and Energy Balance

At **commercial scale**, the reference layout processes **~415 kt $\mathrm{a^{-1}}$** (dry) **residual softwood sawdust** into **SAF-range isoparaffins** via C6/C5 sugar extraction, IBN fermentation, and oligomerization/hydrogenation. Co-products are deliberately valorized: **lignin** (as process energy via boiler/CHP and/or off-site as **bitumen substitute**), **ethanol** from C5 sugars, **fermentation sludge** (K/Ca fertilizer credit), and **microbial biomass** (animal-feed protein).

Annual mass flows (indicative, SAF campaign):
— **SAF: ~30.2 kt $\mathrm{a^{-1}}$** (plant reference product)

— **Lignin (total): ~165 kt $\mathrm{a^{-1}}$ (dry)**; of this, **~105.8 kt $\mathrm{a^{-1}}$** is used **energetically** in the **LI-CHP + RES** best-case to cover thermal demand, with the remainder available for off-site material substitution.

— **Ethanol (from C5): ~28 kt $\mathrm{a^{-1}}$** (credit via energy allocation)

— **Sludge (fertilizer K/Ca): ~89.2 kt $\mathrm{a^{-1}}$; Microbial biomass (animal feed): ~6.8 kt $\mathrm{a^{-1}}$.**

Utilities intensities (per unit SAF): electricity ≈ **0.99 $\mathrm{MJ_{el}}$ / $\mathrm{MJ_{SAF}}$**, steam ≈ **1.266 $\mathrm{MJ_{th}}$ / $\mathrm{MJ_{SAF}}$** (conversion + purification dominate), which makes the **utilities concept** (lignin boiler/CHP vs. fossil boilers; EU-28 vs. high-RES grid) the decisive lever for cradle-to-gate impacts.

Lignin-to-energy requirement: to close the site heat balance, the plant needs **≈ 2.74 t lignin / $\mathrm{t_{SAF}}$** with a lignin **boiler**, or **≈ 3.50 t lignin / $\mathrm{t_{SAF}}$** with **CHP** (higher electric self-sufficiency). Choice of utilities set-up trades off **grid imports** vs. **on-site renewable share** and strongly shifts both **GHG** and **primary energy** allocation.

Allocation snapshot (EU RED II, LHV-based, per t SAF): the energy allocation splits roughly **SAF 22.3%, lignin 63.3%, ethanol 12.6%, animal-feed biomass 1.7%**—driving the distribution of burdens and credits in the fact-sheet.

Environmental headline (for context): in the **LI-CHP + RES** scenario, **SAF** reaches **~6.6 gCO_2-eq / MJ (RED II)**—a **~92.9%** reduction vs. the **94 gCO_2-eq / MJ** fossil comparator. ISO-based scenarios span **~18-56 gCO_2-eq / MJ** depending on energy supply and co-product handling.

Table 2: Summary of main parameters for the SAF case study biorefinery.

Item	Value / note
Feedstock (dry sawdust)	**~415 kt a^{-1}** regional supply concept; trucked (~50 km typical).
Main product (SAF)	**~30.2 kt a^{-1}** isoparaffins (ASTM D7566 annex under evaluation).
Co-products	**Lignin ~165 kt a^{-1}** (dry); **Ethanol ~28 kt a^{-1}**; **Sludge ~89.2 kt a^{-1}**; **Biomass ~6.8 kt a^{-1}**.
Utilities intensity (SAF block)	**0.99 MJ$_{el}$ / MJ$_{SAF}$, 1.266 MJ$_{th}$ / MJ$_{SAF}$.**
Lignin for site energy	**~105.8 kt a^{-1}** (LI-CHP + RES best-case); equivalently **2.74-3.50 t lignin / t$_{SAF}$** (boiler vs. CHP).
Energy allocation (RED II)	**SAF 22.3%, Lignin 63.3%, Ethanol 12.6%, Animal-feed 1.7%** (per t SAF).
System energy set-ups	**NG boiler/CHP** or **lignin boiler/CHP**; grid: **EU-28** or **high-RES** scenario.
State of technology / site concept	**Demo integration**; **Europe/Baltic state** layout for logistics/energy benchmarking.

Interpretation. This **SAF-oriented sugar platform** trades a liquid energy carrier at the gate for **drop-in jet fuel**, with **utilities design and lignin routing** dominating both the **mass** (lignin use) and **energy** (electricity/steam) balances—and, consequently, **GHG** and **PED** outcomes

Table 3: Key characteristics case study.

4-PLATFORM (Isobutene, C5-stream, lignin, vinasse) biorefinery plant using woody residues for the production of sustainable aviation fuel, lignin-blend asphalt, ETBE, fertilizer, process steam and electricity							
State of technology				Demo			
Country				Europe/Baltic states			
Main data source				Literature			
Products	Isooctane	1	MJ_{ION} MJ_{ION}^{-1}	Primary energy demand			
		30.5	Kt a^{-1}	Isooctane	Electricity	0.843	MJ_{el} MJ_{IBN}^{-1}
	ETBE	0.81	MJ_{ETBE} MJ_{ETBE}^{-1}		Steam	1.229	MJ_{el} MJ_{IBN}^{-1}
		35	Kt a^{-1}	ETBE	Electricity	0.54	MJ_{el} MJ_{ETBE}^{-1}
	SAF	1	MJ_{SAF} MJ_{SAF}^{-1}		Steam	0.841	MJ_{th} MJ_{ETBE}^{-1}
		35	Kt a^{-1}	SAF	Electricity	0.99	MJ_{el} MJ_{SAF}^{-1}
					Steam	1.266	MJ_{th} MJ_{SAF}^{-1}
Total emissions	ION BC	80.1	gCO_2eq MJI_{ION}^{-1}	Feedstock saw dust (dry)	Isooctane	5.78	MJ_{DM} MJ_{IBN}^{-1}
Total emissions	ION LI- CHP RES	5.6	gCO_2eq MJ_{ION}^{-1}			415	Kt a^{-1}
Savings	Compared to fossil fuel reference of 94 gCO_2eq MJ^{-1}	94.1	%		ETBE	5.771	$MJ_{DM}MJ_{ETBE}^{-1}$
GHG Emissions	ETBE BC	69.4	gCO_2eq MJ_{ION}^{-1}			415	Kt a^{-1}
Total emissions	ETBE BC RES	25.6	gCO_2eq MJ_{ION}^{-1}		SAF	5.889	MJ_{DM} MJ_{SAF}^{-1}
Savings	Compared to fossil fuel reference of 94 gCO_2eq MJ^{-1}	72.8	%				
Total emissions	SAF BC	88.5	gCO_2eq MJ_{ION}^{-1}				
	SAF LI-CHP RES	6.6	gCO_2eq MJ_{ION}^{-1}				
Savings	Compared to fossil fuel reference of 94 gCO_2eq MJ^{-1}	92.9	%				

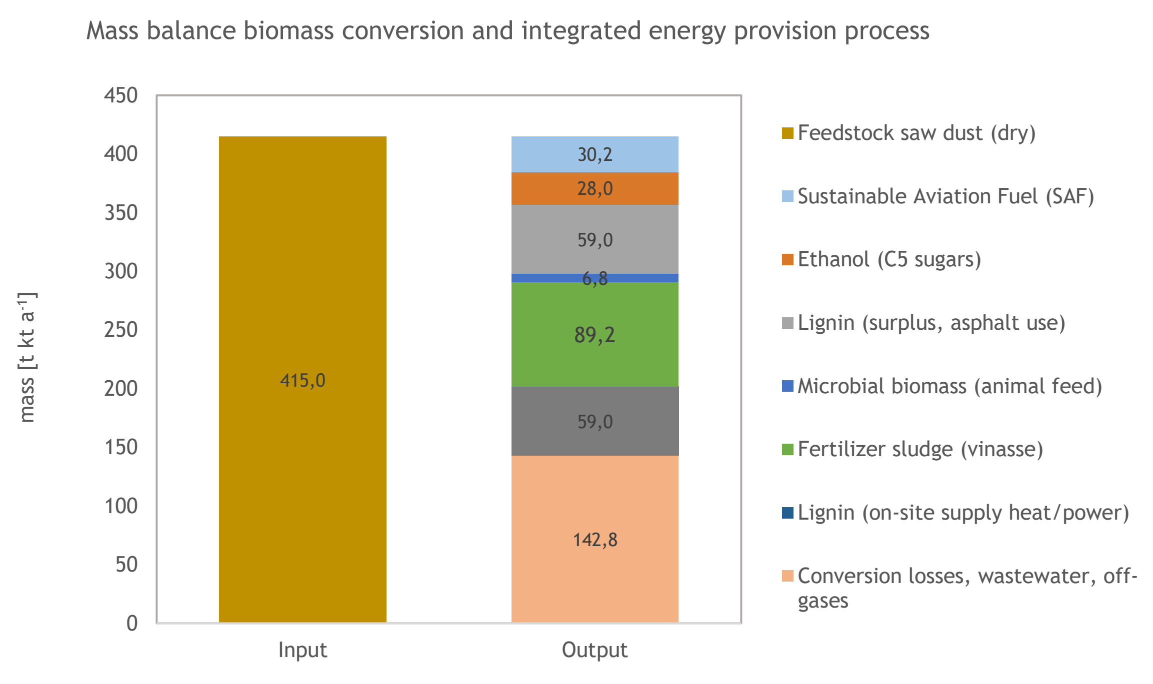
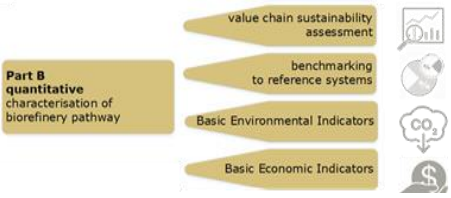


Figure 2: Simplified balance of mass of input and output streams.

PART B: VALUE CHAIN ASSESSMENT



In the **SAF configuration**, revenues are led by SAF but materially supported by co-products. At the reference scale (**~30.2 kt SAF a^{-1}** from **~415 kt a^{-1}** dry sawdust), the plant also generates **~165 kt a^{-1} lignin (dry)**, **~28 kt a^{-1} ethanol (from C5 sugars)**, **~89.2 kt a^{-1} fertilizer sludge (vinasse, K/Ca)**, and **~6.8 kt a^{-1} microbial biomass**; in lignin-CHP layouts, about **~105.8 kt a^{-1}** of the lignin is used on-site to supply process heat/power (utilities intensity ≈ **0.99 MJ_{el}/MJ_{SAF}** and **1.266 MJ_{th}/MJ_{SAF}**), with the remainder available for material markets (e.g., asphalt binder).

Using a **conservative EU pricing** basis, **SAF at ~€2,200 t^{-1}** yields **~€66.4 M a^{-1}** from SAF alone; adding cautious co-product monetization (surplus lignin, ethanol/ETBE route or direct fuel-grade ethanol, animal-feed biomass, a small fertilizer credit, and modest power export) brings total revenue to **~€94-95 M a^{-1}**. Against **~€85 M a^{-1}** in annual costs, corresponding to a dry sawdust price of roughly **50-55 €/t** in the Baltic context, this implies a **modest ~€9-10 M a^{-1} operating margin**—still **sensitive** to SAF price realization and offtake for co-products.[15]

On the **cost side**, the structure is **CAPEX-led** (installed cost **~€598 M**); capital charges are about **~42 %** of annualized cost, **feedstock ~26 %**, with the balance across **utilities/chemicals/maintenance, labor, and overheads**—hence the decisive role of the utilities concept (**lignin boiler/CHP vs. fossil; EU-28 grid vs. high-RES power**) for both **OPEX** and **GHG**.

In certification accounting (RED II), the best-case **lignin-CHP + RES** setup achieves **~6.6 g CO_2-eq/MJ** (≈ **93 %** below the **94 g** fossil comparator); ISO scenarios span **~18-56 g CO_2-eq/MJ**, reflecting the strong sensitivity to energy supply and co-product handling.

In the SAF configuration, **revenues are dominated by SAF sales**, with the **minimum selling price (MSP) ≈ 2,200 € t^{-1}** used as the benchmark in the fact-sheet model. At the reference scale (~**30.2 kt SAF a^{-1}**), this corresponds to ~**84.8 M€ a^{-1}** in product revenue; co-product valorization (ethanol from C5 sugars, fertilizer credits from sludge, animal-feed protein, and optional exported electricity) is treated in the margin through allocation/credits rather than as primary sales lines.

Strategically, **bankable SAF offtake**, **secured sawdust contracts**, and **policy value pass-through** (e.g., mandates/credits) remain pivotal; co-product routing (especially **lignin-to-energy**) and a low-carbon electricity mix materially improve both margins and compliance.

Table 4: Approximated revenue table based on simplified mass and energy balance and literature values[16,17]

Stream	Output (kt/yr)	price assumed (€ per tonne)	Revenue (Mio.€/yr)
SAF (main product)	30.2	2,200	**66.4**
Lignin (surplus)	59.0	200	**11.8**
Ethanol (C5 stream)	28.0	500	**14.0**
Microbial biomass (animal feed)	6.8	200	**1.36**
Fertiliser sludge (vinasse)	89.2	10	**0.89**
Energy export (electricity/steam)	-	-	**1.0**
Total Revenue	-	-	**≈ 94.5**

Figure 3 illustrates the annual **revenue-cost structure** of the SAF-oriented biorefinery. In the **conservative EU/Baltic context**, SAF remains the lead revenue stream (≈**€66.4 M a^{-1}** at ~€2,200 t^{-1} for ~30.2 kt a^{-1} output), while **co-products**—surplus **lignin** routed to asphalt binder markets, **ethanol** from the C5 stream (direct sale or ETBE route), **microbial biomass** (animal feed), a small **fertilizer** credit from vinasse, and limited **power export**—lift total revenues to about **€94-95 M a^{-1}**. On the **cost side**, the structure is **CAPEX-led** (installed CAPEX ≈ **€598 M**), with capital charges contributing ~**42 %** of annualized costs, **feedstock** ~**26 %**, and the remainder spread across **utilities/chemicals/maintenance, labor, and overheads**—hence the central role of the **utilities concept** (lignin boiler/CHP vs. fossil; EU-28 grid vs. high-RES power) in both **OPEX** and **GHG** performance. Under these assumptions, total annual costs of ≈**€85 M a^{-1}** yield a **modest ~€9-10 M a^{-1}** operating margin that is **sensitive** to realizable SAF price and co-product offtake.

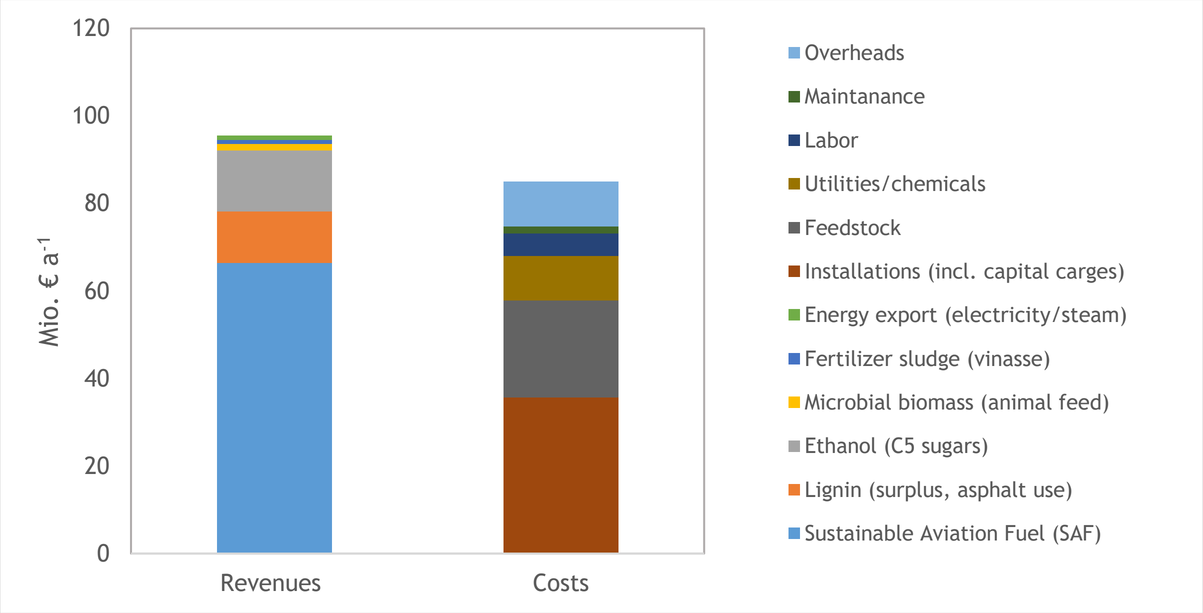


Figure 3: Revenues and costs estimated for sustainable aviation fuel oriented case study.

Recent literature shows that **regional feedstock economics** are a primary determinant of lignocellulosic biorefinery performance: differences in raw-material price and logistics strongly shape TEA outcomes, corresponding to a dry sawdust price of roughly **50-55 €/t** in the Baltic context. While **self-supplied process energy** from co-products (notably **lignin** to boiler/CHP) delivers both environmental and cost benefits. In our SAF case, the **cost pie** mirrors this: approximately **~42 % capital charges**, **~26 % feedstock**, with the **balance** across **utilities/chemicals/maintenance, labor, and overheads**—underscoring that the **utilities concept** (lignin boiler/CHP vs. fossil utilities; EU-28 grid vs. high-RES power) is pivotal for both **OPEX** and **GHG** results. A first-order sensitivity confirms that margins are **highly elastic** to **dry sawdust price** and **realizable SAF price/MSP**: a combined shock of **+25 % feedstock / −10 % SAF price** pushes the plant **negative**, whereas moderate MSP uplift and/or discounted feedstock swings restore a slim positive margin. This is consistent with our broader findings that **lignin-to-energy** and **low-carbon electricity** materially stabilize costs and enable certification-grade performance (best-case **LI-CHP + RES ≈ 6.6 g CO_2-eq/MJ**, ~93 % below RED II's 94 g comparator).

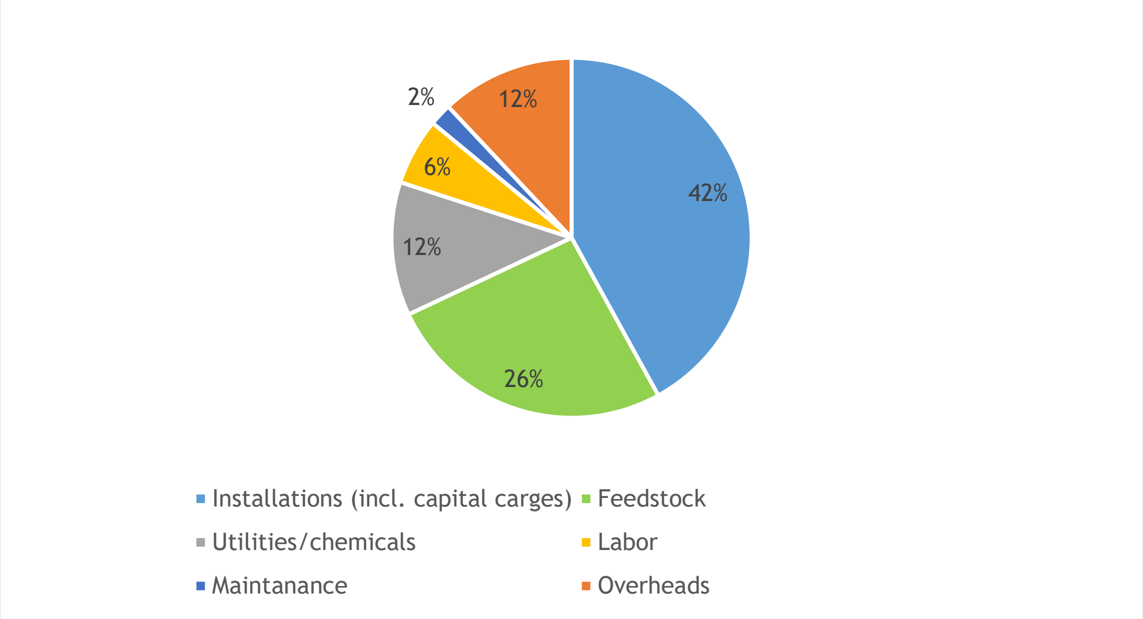


Figure 4: Cost share (SAF configuration. (see Table 3)

The shares in Figure 4 reflect the structure above: **~42 % installation/capital**, **~26 % feedstock**, remainder split across **OPEX (utilities, chemicals, maintenance), labor, and overheads**. Because pretreatment/hydrolysis and upgrading are energy intensive (**≈ 0.99 MJ_{el}/MJ_{SAF}** and **≈ 1.266 MJ_{th}/MJ_{SAF}**), choosing **lignin-boiler/CHP with RES power** limits fossil exposure and supports both **cost** and **GHG** performance; conversely, reliance on fossil boilers and/or carbon-intensive grids raises both.

Base: as-is feedstock; MSP per scenario. **Optimistic:** feedstock −20 %; MSP +10 %. **Pessimistic:** feedstock +25 %; MSP −10 %. **Outcome: breakeven/slim +** at base, **notable margin** in the optimistic case, and **negative** under the combined adverse shock—mirroring prior evidence that regional feedstock markets dominate TEA variance and that **on-site lignin energy** provides both environmental and economic hedges.

Table 5: *Simplified sensitivity (conservative, SAF configuration)*

Parameter	Base	Optimistic	Pessimistic
Sawdust cost (€/t, dry)	55	44 (−20%)	69 (+25%)
SAF price / MSP (€/t)	2,200	2,420 (+10%)	1,980 (−10%)
Total revenue (M€/yr)	95.5	102.1	88.8
Total cost (M€/yr)	85.0	80.6	90.5
Net margin (M€/yr)	+10.5	+21.5	−1.7

Assumptions & notes:

- Outputs: ~30.2 kt/yr SAF; co-products monetized conservatively (lignin, ethanol/ETBE, feed, fertilizer, modest power export).
- Base revenues: SAF €2,200/t ⇒ €66.4 M/yr; plus co-products ⇒ €95.5 M/yr total.
- Base costs: €85.0 M/yr (cost pie ≈ 42% capital, 26% feedstock, balance OPEX/labor/overheads).
- Feedstock sensitivity: feedstock is ~26% of total cost (≈€22.1 M/yr).
    - Optimistic (−20%): cost ↓ by ~€4.42 M to €80.6 M/yr.
    - Pessimistic (+25%): cost ↑ by ~€5.53 M to €90.5 M/yr.
- SAF price sensitivity applies only to SAF revenue (base €66.4 M):
    - +10% ⇒ +€6.64 M; −10% ⇒ −€6.64 M.
- Co-product revenues are held constant across scenarios (conservative).

The plant **tips negative** under the combined **+25% feedstock / −10% SAF price** shock (−€1.7 M/yr). Moderate improvements (e.g., **+10% SAF price** and/or **−20% feedstock cost**) lift the margin to **€20 M+**. This underscores the dominance of **feedstock economics** and **SAF price realization**, and the stabilizing role of **lignin-to-energy** and **low-carbon utilities** on both OPEX and certification-grade GHG results.

Strategic levers for economic viability (SAF):

Co-product strategy. Route **lignin to boiler/CHP** to cover site heat (and part of power) and claim **RED II energy-allocation benefits**; market **excess lignin** as **bitumen substitute** when energy demand is covered. Ethanol (from C5), fertilizer, and animal feed provide additional credits.

Utilities decarbonization. LI-CHP + RES scenarios minimize GHG (~**6.6 $gCO_2e\ MJ^{-1}$**, ~**92.9 %** vs. fossil reference) and reduce exposure to fossil energy price shocks; designs with fossil utilities show higher emissions and often higher variable costs.

Scale & learning. Larger trains and maturing vendor ecosystems **shift CAPEX and OPEX down over time**, closing part of the price gap to fossil jet.

Value-chain/market implications

- **Offtake matters.** Bankable **SAF offtake** (airlines/fuel suppliers) is essential to underwrite the capital stack; campaign flexibility toward **ION or ETBE** can improve early-years cash flow but may conflict with SAF mandate opportunities.
- **Policy alignment.** The case study is modeled against **EU RED II** allocation rules; trajectory to **RED III / CORSIA** compliance plus **RefuelEU-style** mandates are critical to close the price gap in the medium term.
- **Design choice = economics.** Selecting **LI-CHP + RES** not only enables the ~**6.6 $gCO_2e\ MJ^{-1}$** cradle-to-gate result but also **stabilizes OPEX**, improving resilience to fuel-price volatility.

Bottom line: In today's market, the **SAF campaign** shows **tight economics but clear decarbonization value. Capital efficiency**, **co-product monetization**, and **renewable utilities integration** are the decisive levers for investment-grade viability.

Figure 8 presents a simplified flow diagram of the **SAF pathway** (residual softwood → C6/C5 sugars → bio-isobutene → oligomerization/hydrogenation → **SAF-range isoparaffins**) alongside a **fossil jet benchmark**. Beyond the headline product, the figure highlights the **bankability triad** that must be locked in **before FID**: (i) **long-term SAF offtake** with airlines/fuel suppliers (typically take-or-pay, indexed to jet price with floors/ceilings and pass-through of policy credits), (ii) **secure feedstock**

supply from regional sawmills (volume/quality specs and price indexation), and (iii) a **utilities strategy**—preferably **lignin-to-boiler/CHP with RES power**—to stabilize OPEX and underpin GHG performance. The project only closes if these legs are **contracted in parallel**: airlines will not sign meaningful SAF offtakes without credible plant delivery and cost visibility, while investors will not fund the plant without binding offtakes and de-risked feedstock. Co-product routing (lignin to energy or material markets, C5-to-ethanol, fertilizer and animal-feed credits) is shown because it materially supports margins and compliance. In practice, **synchronized agreements**—SAF offtake, feedstock contracts, and utilities/credit arrangements—have been **decisive for value-chain formation**, replacing the “oil boiler + fuel guarantee” logic of fast-pyrolysis heat markets with **aviation-grade, certification-aligned offtakes** and embedded policy instruments.

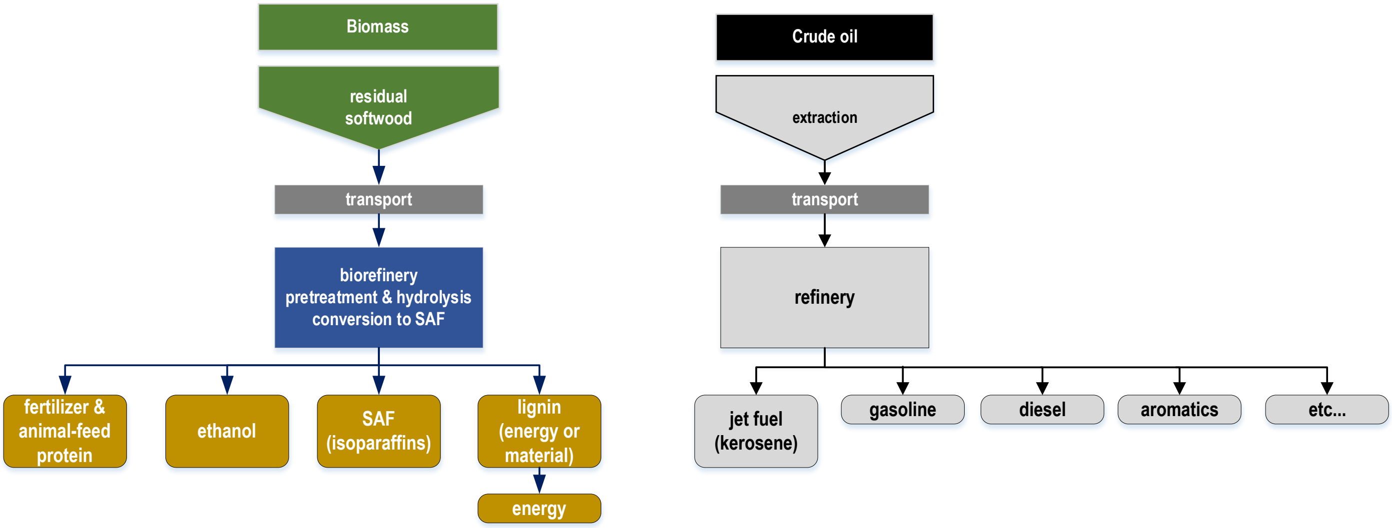


*Figure 5: Flow chart of the **wood-to-IBN SAF biorefinery** with co-product valorization and policy/market interfaces, shown against a **fossil jet refinery reference** (functional equivalence at the blended jet-fuel gate).*

Figure 9 compares the **wood-to-IBN** → **SAF** biorefinery with a fossil jet benchmark. In our ISO 14040/44 cradle-to-gate LCA, **SAF pathway emissions span ~18.7-56 g CO_2-eq/MJ**, driven primarily by the **wood-to-sugars** unit, **off-site auxiliaries**, and—most critically—the **utilities set-up** (lignin-to-energy vs. fossil heat; EU-28 power vs. high-RES mix). Switching to **renewable electricity (RES)** and using **lignin for process heat/CHP** consistently shifts results to the low end of the range. Under certification accounting (**EU RED II**), the best-case **SAF LI-CHP + RES** scenario achieves **~6.6 g CO_2-eq/MJ**, i.e., **~92.9%** below the **94 g CO_2-eq/MJ** fossil comparator. All scenarios also satisfy **CORSIA**’s ≥10% reduction vs. **89 g CO_2-eq/MJ** fossil jet, with the same design levers (lignin-to-energy, RES power) delivering the largest margins. On energy use, the **allocated PED** is **~2.8-4.2 MJ/MJ SAF** (renewable share up to **~82%** in lignin-CHP designs), while the **non-allocated biorefinery PED** is **~10.7-13.1 MJ/MJ SAF**. Overall, **electricity carbon intensity** and **lignin routing** are the dominant determinants of both **GWP** and **PED**; without a low-carbon grid, several layouts fail RED II savings, whereas **LI-(B/CHP)+RES** configurations meet or exceed the target.

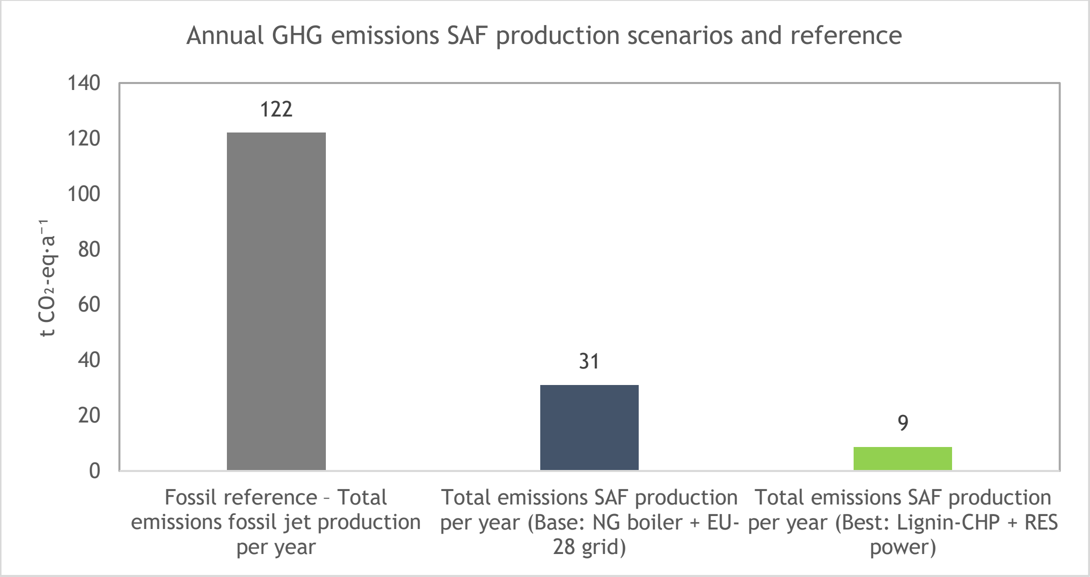


Figure 6: Annual GHG Emissions of SAF production scenarios under base and best utilities scenarios relative to fossil jet fuel

Table 6: Overview of GHG emissions and reductions in the SAF case (production & application).

Contribution to GHG (cradle-to-gate)	Base caseNG boiler + EU-28 grid	Best caseLignin-CHP + RES power
Biomass supply & transport	1.8	1.8
Pretreatment & enzymatic hydrolysis	5.2	1.3
Fermentation (bio-IBN) & purification	3.1	0.9
IBN upgrading to SAF (oligomerization/hydrogenation)	2.0	0.6
Utilities (process heat & electricity)	10.5	1.9
Off-site auxiliaries (handling, storage, services)	1.3	0.5
Product transport to blender/airport (regional)	0.2	0.2
Co-product credits (fertilizer & animal-feed protein)*	−0.2	−0.6
Total — SAF production (cradle-to-gate)	23.9	**6.6
Tank-to-wake combustion (biogenic CO_2 under RED II)	0.0	0.0
Total — production & application (RED II view)	23.9	6.6
Fossil jet comparator (RED II)	94	94
GHG reduction vs. fossil jet	74.6 %	92.9 %

* Co-product handling follows your hybrid approach: energy-based allocation among energy products (SAF, ethanol, lignin) and avoided-burden credits for non-energy co-products (fertilizer and animal-feed protein).

Notes for the caption:

- The **best-case result (6.6 g CO_2-eq/MJ)** corresponds to **lignin-to-CHP with renewable electricity (RES)**; the **base case** uses **natural gas utilities and EU-28 average grid electricity**.
- If you also report **ISO 14040/44** results, keep those in the text/Figure 9 (range ~18-56 g CO_2-eq/MJ) to show methodological sensitivity; Table 5 stays **RED II** for certification comparability.

*Table 7: Overview of the TEE assessment results — **SAF** case study.*

Block	Metric	BaseNG boiler + EU-28 grid	BestLignin-CHP + RES
Greenhouse-gas emissions	g CO_2-eq per MJ SAF (cradle-to-gate, RED II)	**23.9**	**6.6**
	Annual GHG — biorefinery (t CO_2-eq·a^{-1})*	**31,100**	**8,600**
	Fossil jet comparator (t CO_2-eq·a^{-1}; 94 g/MJ)	122,000	122,000
	Savings vs fossil jet	**~74.6 %**	**~92.9 %**
Cumulated energy demand (PED)	Allocated PED (MJ/MJ SAF)	**~4.2**	**~2.8**
	Annual allocated PED (TJ·a^{-1})	**~5,450**	**~3,630**
	Renewable share of PED	**moderate**	**high (lignin + RES)**
Costs	Annual costs (M€·a^{-1})**	**~82-86**	**~78-82**
	Specific revenue SAF (€/t SAF)	**~2,200**	**~2,200**
	Investment (installed CAPEX, M€)	**~598**	**~598**
Revenues	Annual SAF revenue at MSP (M€·a^{-1})†	**~66.4**	**~66.4**
	Specific revenue (€/t SAF)	**2,200**	**2,200**
	Specific revenue (€/L SAF, ρ≈0.775 kg·L^{-1})	**~2.16**	**~2.16**

* Annual GHG totals = (g CO_2-eq/MJ) × (1.298×10^9 MJ·a^{-1}); fossil reference uses **94 g CO_2-eq/MJ**.

** Cost bands reflect financing assumptions; capital charges dominate the total, with feedstock as the second-largest block.

† MSP used for the fact-sheet baseline; co-product effects (ethanol, fertilizer, animal-feed protein, optional power export) are handled by allocation/credits rather than shown as independent sales lines.

Reading notes.

- The **Best** layout (lignin-CHP + RES) delivers the certification-oriented **6.6 g CO_2-eq/MJ** cradle-to-gate result and materially lowers **PED** by displacing fossil utilities with **lignin** and low-carbon power.
- The **Base** layout is margin-constrained and sensitive to both **sawdust price** and **grid carbon intensity**; moving to **lignin-CHP** improves both **GHG** and **OPEX stability**.
- Investment-grade viability hinges on **bankable offtake**, **secure feedstock contracts**, and **co-product valorization**—especially the routing of **lignin** to on-site energy.

5. Conclusions & strategic outlook

Key conclusions

Technical performance

- The demonstrator-scale, residue-based **wood-to-IBN → SAF** biorefinery is **technically feasible** and operable in continuous mode.
- At the reference scale (**~415 $kt \cdot a^{-1}$ dry sawdust**), the plant delivers **~30.2 $kt \cdot a^{-1}$ SAF** with campaign flexibility to **ION/ETBE**, while **lignin** supplies process heat (boiler) or heat+power (CHP).
- **Co-product valorization**—lignin (energy or bitumen substitute), **C5-to-ethanol**, **fertilizer** (K/Ca from sludge), and **animal-feed protein**—is integral to mass/energy closure and site economics.
- The **utilities concept** (lignin-CHP vs. fossil, RES vs. EU-28 grid) is the dominant design lever for both **GHG** and **OPEX**.

Environmental impact

- **Cradle-to-gate GHG** for SAF spans **~18-56 g CO_2-eq/MJ (ISO)** depending on utilities and allocation; under **RED II** accounting, the **lignin-CHP + RES** layout achieves **~6.6 g CO_2-eq/MJ**, i.e., **~93%** below the **94 g CO_2-eq/MJ** fossil comparator.
- All modeled layouts meet **CORSIA**’s reduction threshold; **electricity carbon intensity** and **lignin routing** are the principal drivers.
- **Primary energy demand (PED)** is lowest—and the renewable share highest—when **lignin supplies process energy** and grid imports are **RES-based**.

Economic viability

- Economics are **tight but bankable** with the right conditions: **long-term SAF offtake**, **secured sawdust contracts**, **policy credit stacking**, and **lignin-to-energy** integration.
- **CAPEX** dominates annualized costs; **feedstock** is the second-largest component. The baseline **MSP ~2,200 €/t SAF** yields a **slim operating margin** that is highly sensitive to **feedstock price** and **achieved SAF price**.
- Co-product credits (ethanol, fertilizer, animal feed, optional power export) improve the margin but do not replace the need for **policy support** and **efficient financing**.

Strategic outlook

Policy integration

- **RefuelEU-style SAF mandates**, **GHG-based credits (RED/CORSIA)**, and **ETS/CBAM interactions** are pivotal to closing the price gap to fossil jet.
- Contract structures that pass through **policy value** (e.g., book-and-claim, base-price floors, indexation to jet) de-risk revenue and enable financing.

Scale-up pathway

- Replicable **train-based designs** and **regional clusters** (co-located with sawmills, logistics hubs, and grid interconnects) are the fastest route to scale.
- Moving from **boiler to CHP**, increasing **on-site RES**, and standardizing vendors reduce both **GHG** and **unit costs** over time.

Innovation levers

- **Higher hydrolysis and fermentation yields**, **lower-severity upgrading**, and **catalyst longevity** directly cut utilities demand.
- **Green H_2 integration** and **power-to-heat** (as grids decarbonize) further lower cradle-to-gate emissions.
- Continued progress toward **ASTM D7566 annex inclusion** for IBN-derived isoparaffins expands market access and blend limits.

Comparative positioning

- Versus **HEFA**, the pathway avoids lipid-feedstock constraints and ILUC exposure; versus **FT-biomass**, it offers **modular integration** and strong co-product synergies; versus **ATJ-ethanol**, it benefits from **solid-residue feedstock security** and diversified product campaigns (SAF/ION/ETBE).

Final remark

- The **wood-to-IBN SAF** biorefinery demonstrates a credible, **residue-based** route to deep aviation decarbonization. With **bankable offtake**, **secured feedstock**, and **renewable utilities**, the concept delivers **>90% GHG savings** under certification accounting and establishes a pragmatic blueprint for **industrial-scale, circular-bioeconomy deployment**.

Abbreviations

ATJ – alcohol-to-jet (SAF pathway based on alcohols such as ethanol or isobutanol); BC – base case; CAPEX – capital expenditure; CBAM – Carbon Border Adjustment Mechanism; CHP - combined heat and power; CORSIA – Carbon Offsetting and Reduction Scheme for International Aviation; ETBE – ethyl tert-butyl ether; FID – final investment decision; GHG – greenhouse gas(es); GWP - global warming potential; IBN – isobutene (bio-isobutene); IEA – International Energy Agency; IRR - internal rate of return; ISO – International Organization for Standardization; LCA – life cycle assessment; LCI – life cycle inventory; LHV - lower heating value; LI-CHP - lignin-fired combined heat and power; MSP - minimum selling price; NG – natural gas; OPEX – operating expenditure; PED – primary energy demand; RED II / RED III – Renewable Energy Directive II / III; RES – renewable electricity supply / renewable energy sources; SAF – sustainable aviation fuel; SARPs – Standards and Recommended Practices (ICAO); SIP – synthetic iso-paraffins (ASTM D7566 Annex 3); TEA – techno-economic assessment; TEE - Technical-Economic-Environmental assessment; TRL – technology readiness level.

MORE DETAILED INFORMATION ON THE DATA BASIS AND THE METHOD APPLIED ARE AVAILABLE IN THE ACCOMPANYING REPORTS AT HTTPS://TASK42.IEABIOENERGY.COM/DOCUMENT-CATEGORY/REPORTS-PAPERS/

This case study was prepared by Johannes Lindorfer and colleagues from the Energieinstitut at the Johannes Kepler University Linz, Austria.

Appendix A: Data basis and calculations used in the TEE fact sheet

This appendix summarises the key assumptions, calculations, and primary sources underpinning the case study.

Table A1. Key assumptions, calculations, and references used in the SAF case study (residual softwood → sugars → bio-isobutene → isoparaffins)

Block	**Parameter**	**Symbol / unit**	**Value (base case)**	**Value (best case)**	**Notes**
Capacity & operation	Nominal operating hours	$h \cdot a^{-1}$	8,000	8,000	Planned on-stream factor for commercial operation
	Feedstock throughput (dry sawdust)	$kt \cdot a^{-1}$	**~415**	**~415**	Regional softwood residues (sawmill/sanding dust); dry basis
	Main product output (SAF isoparaffins)	$kt \cdot a^{-1}$	**~30.2**	**~30.2**	Reference SAF campaign; other campaigns possible (ION/ETBE)
	SAF energy output (LHV≈43 $MJ \cdot kg^{-1}$)	$TJ \cdot a^{-1}$	**~1,298**	**~1,298**	30.2 kt × 43 $GJ \cdot t^{-1}$
Co-products	Lignin (total produced)	$kt \cdot a^{-1}$ (dry)	**~165**	**~165**	Portion used for process energy vs. sold depends on utilities concept
	Lignin used for site energy	$kt \cdot a^{-1}$	–	**~105.8**	Best case uses lignin in CHP to meet heat (+part power)
	Ethanol (from C5 sugars)	$kt \cdot a^{-1}$	**~28**	**~28**	Energy product under RED allocation
	Fermentation sludge (fertilizer credit)	$kt \cdot a^{-1}$	**~89.2**	**~89.2**	Credited via avoided mineral fertilizer (K/Ca)
	Microbial biomass (animal-feed credit)	$kt \cdot a^{-1}$	**~6.8**	**~6.8**	Credited as protein feed
Utilities & energy	Utilities concept	–	**NG boiler + EU-28 grid**	**Lignin-CHP + RES power**	Two bounding designs used throughout the TEE analysis
	Electricity intensity (SAF block)	MJ_{el} per MJ_{SAF}	**~0.99**	**~0.99**	Same process need; supply differs (grid vs. CHP/RES)
	Annual electricity demand	$GWh \cdot a^{-1}$	**~357**	**~357**	0.99 × 1.298×10^9 MJ ÷ 3.6
	Steam/thermal intensity (SAF block)	MJ_{th} per MJ_{SAF}	**~1.266**	**~1.266**	Conversion + purification dominate

Block	Parameter	Symbol / unit	Value (base case)	Value (best case)	Notes
	Annual steam/thermal demand	$GWh_{th}\cdot a^{-1}$	**~456**	**~456**	$1.266 \times 1.298\times10^{9}$ MJ ÷ 3.6
GHG performance (RED II accounting)	Fossil comparator	$g\ CO_2\text{-eq}\cdot MJ^{-1}$	**94**	**94**	RED II reference for aviation
	SAF cradle-to-gate	$g\ CO_2\text{-eq}\cdot MJ^{-1}$	**~23.9**	**~6.6**	Base vs. best utilities designs
	Reduction vs. fossil	%	**~74.6%**	**~92.9%**	Relative to 94 $g\ CO_2\text{-eq}\cdot MJ^{-1}$
LCA scope & allocation	Boundary	—	Cradle-to-gate	Cradle-to-gate	Production only; use phase biogenic under RED
	Allocation among energy products	—	LHV-based	LHV-based	For SAF, ethanol, lignin
	Credits for non-energy co-products	—	Avoided-burden	Avoided-burden	Fertilizer & animal-feed protein
Economics (fact-sheet baseline)	Installed CAPEX	M€	**~598**	**~598**	Order-of-magnitude, installed cost
	MSP (SAF)	$€\cdot t^{-1}$	**~2,200**	**~2,200**	Reference price used to balance base-year cash flows
	Annual SAF revenue at MSP	$M€\cdot a^{-1}$	**~66.4**	**~66.4**	30.2 kt × 2,200 $€\cdot t^{-1}$
	Feedstock price (dry sawdust)	$€\cdot t^{-1}$	**~53-55** (illustrative)	**~80**	Sensitivity driver in TEA
	Cost structure (high level)	share of annualized cost	**CAPEX ≈42%; feedstock ≈26%; rest OPEX**	Similar shares	Financing assumptions drive CAPEX share
Standards & certification	Regulatory frameworks	—	RED II, CORSIA	RED II, CORSIA	Accounting and comparators as reported
	ASTM status	—	Emerging annex for IBN-derived isoparaffins	Emerging	Target pathway for D7566 inclusion

Abbreviations: LHV—lower heating value; RES—renewable electricity mix; CHP—combined heat and power; TEA—techno-economic analysis; TEE—Technical-Economic-Environmental.

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