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A Pathway to Support the Expected Demand for Sustainable Aviation Fuel (SAF)

For companies developing gasification + Fischer-Tropsch systems using torrefied pellets, the long-term outlook is favorable.

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FutureMetrics is not expert in the SAF markets. We depend on third-party research to gain our understanding of current and future demand.

However, FutureMetrics is expert at the supply of upgraded biomass derived feedstocks which will be used in the most promising pathway for production of SAF to meet future demand: the Fischer-Tropsch conversion of biogenic carbon into hydrocarbons.

This white paper will begin with a discussion of the SAF markets and then will introduce a new FutureMetrics dashboard. The dashboard is based on a comprehensive model for converting high carbon content woody biomass (torrefied/carbonized) into SAF.

FutureMetrics' has a deep understanding of the wood pellet sector (production and use) and a deep understanding of the thermal treatment processes used for upgrading biomass into the high carbon content feedstock that is the optimal input for a SAF refinery.

The SAF Markets

SAF is an energy dense hydrocarbon. Energy density is critical for aviation fuel. Aircraft that travel moderate distances or more will not be battery-electric driven. The energy density per kilogram of modern Li-ion batteries is about 0.25 kWh/kg. SAF is about 12.0 kWh/kg (nearly 50 times more energy per unit of weight). While battery efficiency per kg will likely improve in coming years, it is highly unlikely that we will see a 50x improvement! Furthermore, as SAF is consumed during flight, the aircraft gets lighter, resulting in lower fuel consumption per distance traveled. Batteries retain 100% of their weight from takeoff to landing[1].

There are technically feasible solutions to operate aircraft with renewable, carbon-free fuels. Hydrogen and anhydrous ammonia would be such fuels. While technically possible the economics for either fuel are prohibitive. In addition to a much lower volumetric energy density , very costly adaptive changes would have to be made to the turbines, the fuel tanks, and the supply logistics.

[1] For example, a 3,000-mile flight would require about 30 tonnes of regular aviation fuel or SAF. Batteries with the same energy would weigh about1,500 tonnes. That is about 5 times the maximum takeoff weight of a Boeing 787 and leaves no room for passengers or cargo.

The only pathway for decarbonization of the aviation sector is to replace geologic carbon-based fuel with biologic carbon-based fuel produced from sustainable sources.

By most accounts, SAF demand will grow from the current ~2-3 million metric tonnes per year to ~40 million tonnes per year in 2035 and, if net zero is to be reached for air travel by 2050, more than300 million tonnes per year[2]. The basis of the expected growth is government policies, carbon emissions regulations, airline net-zero commitments, and an evolution in consumer sensitivity to CO_2 pollution. A key characteristic supporting the growth of the use of SAF is that it is a "drop-in" replacement for fossil fuel derived aviation fuel.

The current supply of SAF is less than 1% of the global aviation fuel demand. Even if actual future demand is significantly less than the forecasts, there is a massive opportunity for growth.

Currently most SAF comes from used animal fats, used cooking oil, and waste with high lipids content that are converted via the HEFA process[3]. But those feedstocks are limited and cannot come close to satisfying the expected long-term demand.

The future supply of SAF will depend on biomass including the residues from the forest products industry[4].

Converting Woody Biomass to SAF

The pathway from biomass carbohydrates to SAF is based on the carbon (C) contained in biomass. A process named Fischer-Tropsch (FT), invented in 1925 by Franz Fischer and Hans Tropsch, links hydrocarbon radical (CH_2) into chains to produce compounds that are essentially identical to classic, crude oil derived aviation fuel. Co-products from the FT process include renewable diesel fuel and lighter fractions such as LPG. (For a representative mass and energy flow diagram, see Figure 3 at the end of this paper. The diagram is AI generated.)

The FT process is not new[5]. There is essentially zero technology risk with FT. The equipment specifications and process flow for the conversion from carbon containing feedstock to SAF is well-established.

But the conversion rates and operating costs can vary. A primary determinant is the carbon content of the feedstock.

The first step in the FT process is gasification. The goal is to produce carbon monoxide (CO) and hydrogen (H_2) that are later reacted to the CH_2 radicals which are the building blocks of the hydrocarbon end products. Feedstocks with higher carbon content and lower moisture content gasify more efficiently and use less oxygen

[2] S&P Global, IATA
[3] See HERE for a discussion of SAF production using the HEFA process.
[4] For a discussion of how the forest products industry can provide a perpetual supply of sustainably sourced biomass, see this webinar by Dr. Strauss sponsored by the Advanced Woody Biomass Alliance on YouTube HERE.
[5] The process was developed on 1926 in Germany and was used to synthesize hydrocarbon fuel from a domestically available source, coal. See HERE.

input. As the gasification typically happens near the synthesis reactors, transporting feedstock with lower moisture and volatiles content to that location is less costly.

The SAF refinery needs consistent feedstock, and prefers feedstock that has high C, low moisture, and low levels of minerals (ash). Delivering the highest carbon content and least unwanted non-carbon components, within technical and economic constraints, will improve the SAF output per tonne of input, and it will lower operating costs.

Doing that with biomass requires specific expertise and experience. SAF refinery operators are not likely to have that expertise.

The experts at converting highly diversified woody biomass inputs (variations in moisture content, species, mineral/ash content, size, etc.) into a homogeneous output are the wood pellet manufacturing plants that made the ~55 million tonnes produced in 2025[6].

Most of those wood pellets are so-called "white" pellets. They are dried and densified wood. But white wood pellets have a relatively low carbon content (typically 47-52%) and contain a number of undesirable compounds . Adding an upgrading step to the wood pellet manufacturing process will produce a feedstock that a SAF refinery will be very happy with.

The additional step over the existing production of "white" wood pellets increases the net carbon content of the output pellets and removes many of the unwanted molecules. It is a thermal treatment process under oxygen-starved conditions at about 280-310C, somewhere between roasting coffee beans and converting coal to coke[7]. The thermal treatment, under starved oxygen conditions, drives off unwanted moisture and compounds and yields a drier product with a higher carbon content

Torrefaction (or if driven to an even higher C content, carbonization) yields a "black", higher carbon content pellet that improves the SAF yield for the same number of input tonnes. It also lowers many other operating challenges and costs compared with input feedstocks that have not been upgraded with torrefaction. Under most scenarios, the net will be a lower cost for the refinery to produce a gallon of SAF.

FutureMetrics has developed a comprehensive model describing the conversion of torrefied pellets into SAF[8]. Figure 1 is derived from that model and it shows that higher torrefaction severity (higher carbon content) yields very positive outcomes for the SAF refinery. For the same mass of feedstock, higher C results in higher production rates and lower production cost per gallon.

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[6] For data to 2024, see FAO data HERE. 2025 data is based on FutureMetrics research.
[7] For more on coking see HERE.
[8] The model is based on review and analysis by FutureMetrics of many versions of the FT mass and energy flows. While similar, they are not all in agreement. The model used herein is a synthesis and may not perfectly correlate with other models. The model's mass and energy flows start with the carbon content of the feedstock. The model is the foundation of the dashboard described later in this paper.

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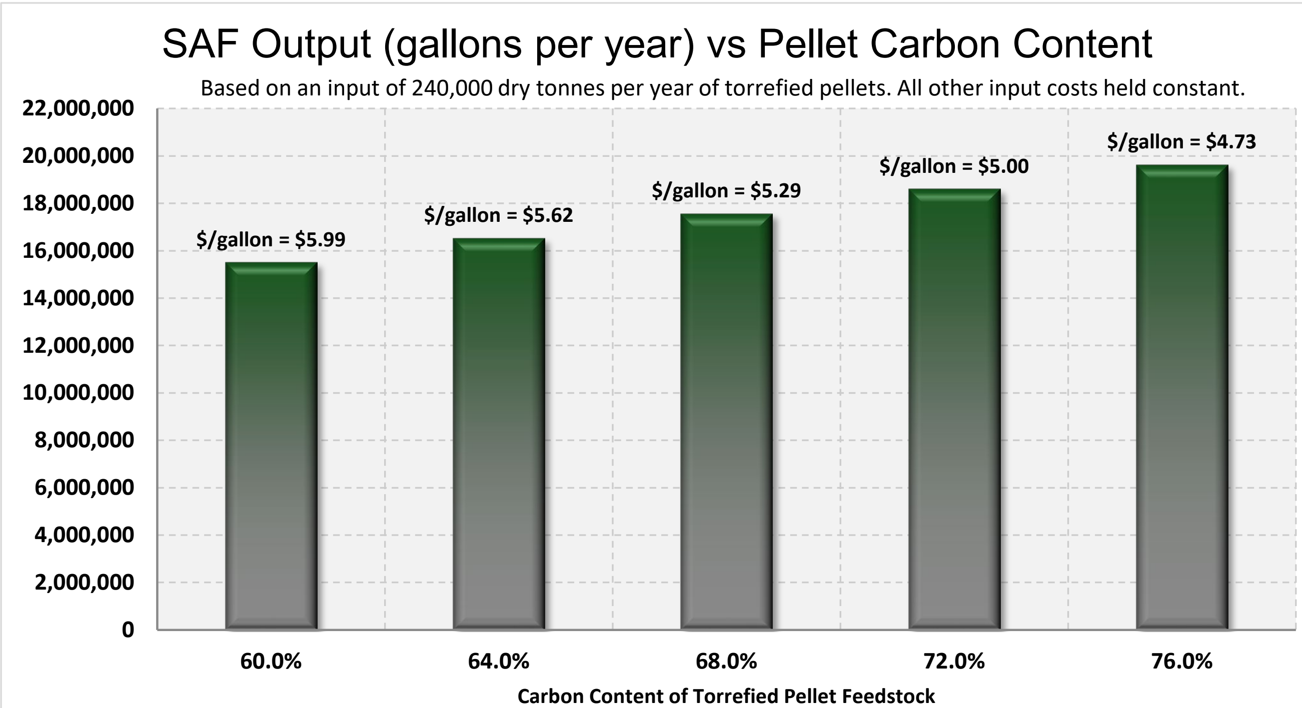

Figure 1 - SAF Output vs Pellet Carbon Content

Higher C content correlates with a higher heating value (HHV) per mass unit.

Some of the mass and energy content of the untreated feedstock (wood) is released in the thermal upgrading of the biomass to a higher C content via torrefaction/carbonization. This energy loss is typically reclaimed to dry the incoming feedstock. Thus, as the C content of the final product increases, more biomass feedstock is needed[9]. As the carbon content of the pellets increases, so does the cost of producing torrefied pellets (more input per unit of output). The chart (Figure 1) says "All other input costs held constant". It is a static view, assuming that there no other changes in costs.

While the chart illustrates the absolute value of a higher C content in the FT input, it does not show the optimal level of C content. That level is a function of the higher cost of the black pellet input and changes in operating costs and process uptime.

There are many inputs to the operating cost for the conversion of torrefied pellets into SAF. Some inputs, such as external hydrogen demand, are dependent on other inputs. For example, for H_2, as the feedstock C content

[9] Based on FutureMetrics analysis, the best solution in most scenarios is to take already produced white pellets and subject them to thermal treatment. This is referred to as torrefaction after pelletization (TAP). TAP is an easy and relatively low cost add-on to an existing white pellet factory.

goes higher, the feedstock will contain fewer hydrocarbon molecules and thus less inherent hydrogen. External hydrogen demand for the FT process will be higher for higher C content feedstock.

The optimization solution for each unique project will not always be the same. There are experts at SAF production using FT that are much better qualified than FutureMetrics at working through the optimization problem.

As noted on page one of this paper, FutureMetrics' expertise is in performing the due diligence on the torrefied pellets that are delivered to a SAF refinery in order to validate the supplier's ability to deliver quantity, quality, and price as promised. As shown below, feedstock cost and characteristics are the dominant driver in the total cost of producing SAF.

To show how inputs impact costs, FutureMetrics has developed an **interactive dashboard** that sits on top of our SAF production model. The dashboard allows you to manually try combinations of input variables and see the impacts of changes on the outputs. It is not a rigorous optimization methodology but it is informative, nonetheless.

Dashboard – Torrefied Pellets to SAF

The dashboard is fully interactive in real time and is free to use at the FutureMetrics website.

There are four chart outputs that you can select. Figure 2 shows how the dashboard opens. The default chart is a cost build-up for a gallon of SAF. Other charts are (2) the cost build-up of total operating costs, (3) the disposition of the pellet input energy into products, by-products, and losses, and (4) the relationship between carbon content and output (as shown in Figure 1 but responsive to changes in input assumptions).

All of the charts are responsive to changes in input assumptions. There are controls (sliders and spinners) that allow you to change most of the important inputs across the processes.

There are separate windows with controls for (1) co-products and exported energy (the process is exothermic), and (2) for the cost of green hydrogen generation. As noted earlier in this paper, as C content increases more external green H_2 is required. Thus, the cost of H_2 matters.

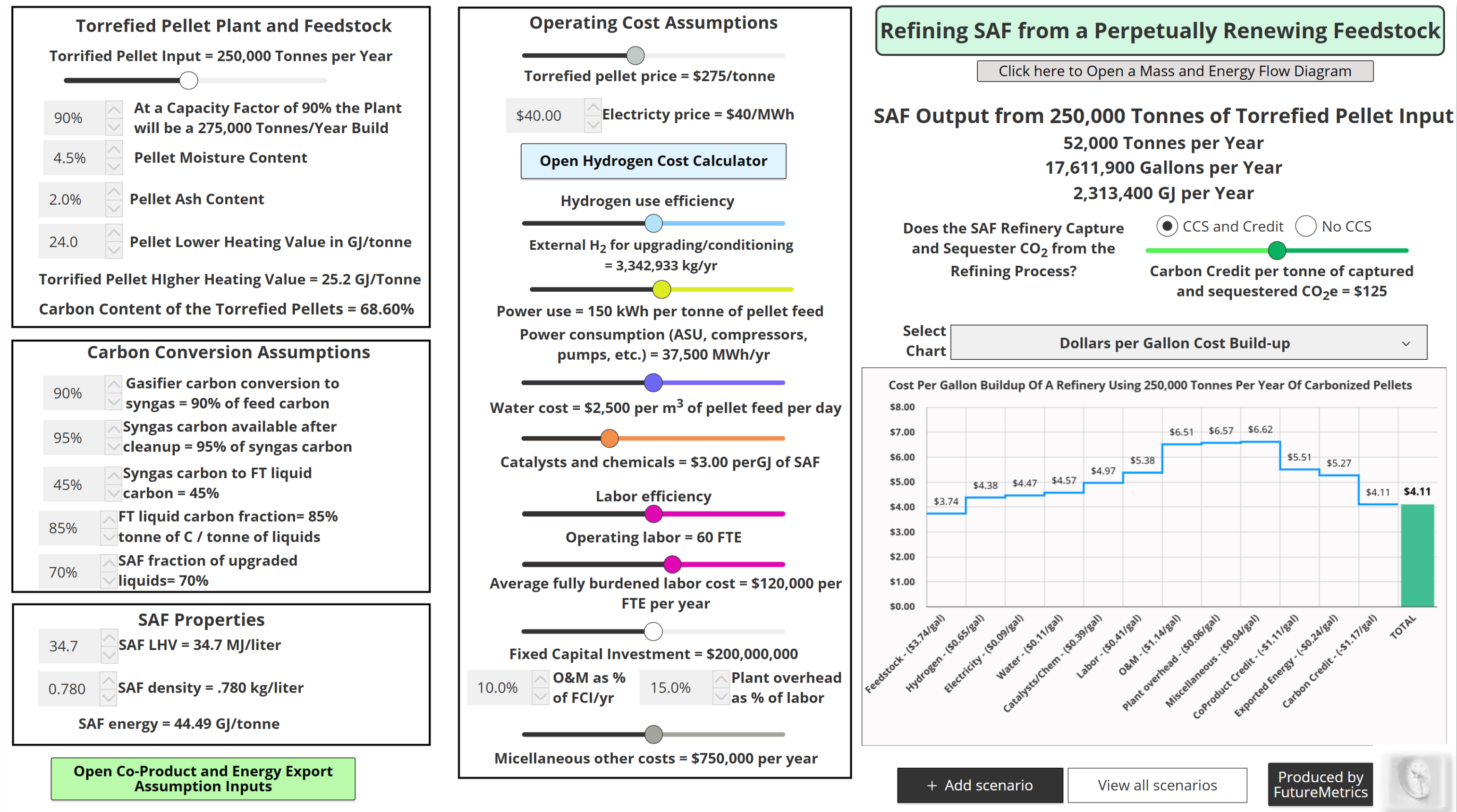

Figure 2 - Torrefied Pellets to SAF Dashboard

There is also a control for toggling a credit for carbon capture being on or off. The FT process generates some CO_2 emissions. If those emissions are captured and sequestered, and there is a price paid to the SAF refinery for carbon capture and sequestration (CCS), that is shown as a credit in the cost build up charts. If toggled on (as shown is Figure 2) then there is also a control to set the value of the sequestered carbon (and thus the value of the credit to the cost of SAF).

A "what-if" exercise using the input for the value on CCS can be a valuable insight into how policy and/or carbon markets can matter to the production of SAF.

The co-products' ratios and prices can be set within the separate window that opens when the green button at the bottom left corner is clicked. Co-products include renewable diesel, LPG, and naphtha.

Conclusion

The expected growth in demand for SAF far outstrips the current production. Growth in output will require building out supply chains for SAF refinery feedstocks. The current major source of input to make SAF, used oils and high lipid wastes, the collection and processing are expensive and insufficient to support the needed growth.

The only currently practical pathway to satisfying future demand is via the use of sustainably sourced biomass (carbohydrates) and hydrogen from renewable sources, from which "green" hydrocarbons can be derived.

And, as this paper has described, leveraging the already mature white pellet sector, and adding thermal treatment equipment to the pellet plants to produce TAP pellets, is a ready-to-deploy and optimal solution for supplying consistent high-carbon feedstock to SAF refineries.

This paper and the dashboard provide an overview of path from wood pellets to FT SAF.

What stands out in the cost build-up analysis is that the cost of the feedstock, and indirectly the cost of the carbon needed to make SAF, is the input that dominates the costs of producing SAF.

Even a modest and persistent mismatch between how the feedstock characteristics for a SAF refinery project are modeled and the actual cost and quality of the torrefied/carbonized pellets can permanently turn profits into losses.

Independent validation of the TAP supply is essential to the risk management of a SAF project that will use thermally upgraded woody biomass as feedstock.

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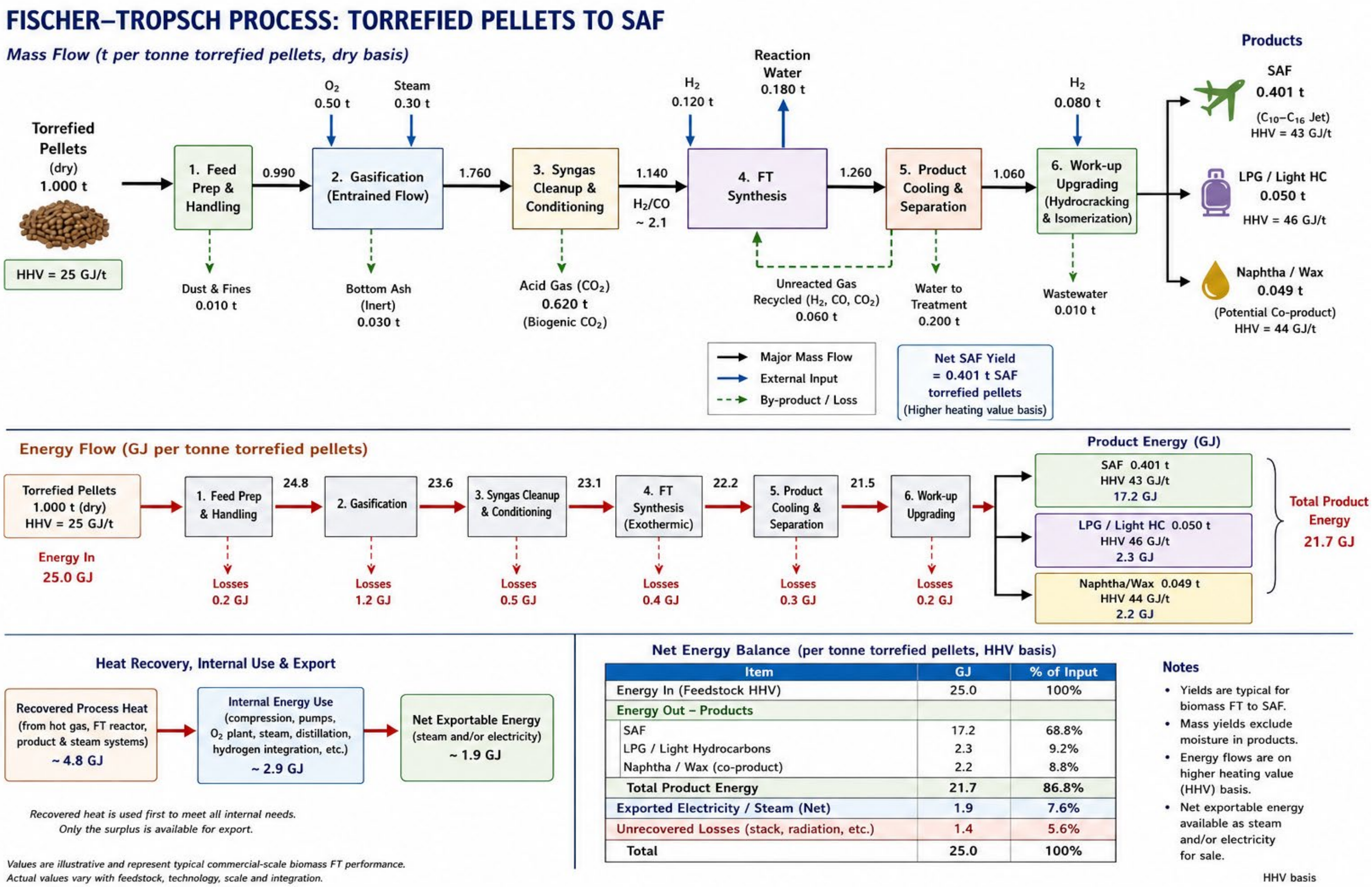

Item	GJ	% of Input
Energy In (Feedstock HHV)	25.0	100%
Energy Out – Products		
SAF	17.2	68.8%
LPG / Light Hydrocarbons	2.3	9.2%
Naphtha / Wax (co-product)	2.2	8.8%
Total Product Energy	21.7	86.8%
Exported Electricity / Steam (Net)	1.9	7.6%
Unrecovered Losses (stack, radiation, etc.)	1.4	5.6%
Total	25.0	100%

Figure 3 - Stylized Schematic of the Mass and Energy Flows - Torrefied Pellets to SAF