SUSTAINABLE AVIATION FUEL — FROM FEEDSTOCK TO FUEL

A PRODUCER-AGNOSTIC PROCESS NETWORK FOR THE FINANCIAL MODELLING OF SAF AND E-SAF

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Companion to Working Paper 01 / 2026 (carbon pricing as a risk factor) and Working Paper 02 / 2026 (the EU ETS cap). Figures and exhibits are generated from the model tables and regenerate when the data changes.

ABSTRACT

The European Union is squeezing aviation from two sides at once. The Emissions Trading System prices the scarcity of the right to emit; ReFuelEU Aviation mandates a rising share of sustainable aviation fuel (SAF) — a fuel that is still barely at commercial scale. Meeting the mandate is therefore not a procurement problem but an industrial one: it requires building, and in places massively upscaling, an interconnected network of feedstock supply, gasification, fermentation, hydrogen and renewable electricity, whose parts compete with food, feed, power and chemicals for the same finite resources.

This paper sets out a producer-agnostic process network that maps the principal certified SAF and e-SAF pathways from feedstock to fuel. The network is mass-balanced and parameterised from public literature, and it is used here to read the financial and economic shape of the problem: where each pathway sits in the wider industrial system, which co-products and cross-industry interactions carry value, and which constraints and caps bind first. A reference calculator inverts the network — given a target SAF volume and type it returns the inputs required, the residuals of those inputs, the side-products of the SAF, and the ceilings approached. The aim is to bring actuarial discipline — explicit quantities, reproducible assumptions and named sources — to decisions about a system that is being reconfigured in real time.

Scope of this draft. The boundary is SAF production — from feedstock to the certified SAF product (neat synthetic paraffinic kerosene for the stand-alone routes; the renewable fraction of the jet stream for co-processing), prior to blending with fossil jet. The model covers the routes at or near commercial scale; experimental routes — algae-based and other early ASTM

annexes among them — are acknowledged but not yet modelled. The focus is the EU; quantities are indicative and public-source-derived. Carbon-intensity values and price dynamics are developed in companion threads and only referenced here.

1. A SYSTEM SQUEEZED FROM BOTH ENDS

Working Papers 01 and 02 in this series treated carbon pricing as a risk factor and reconstructed the EU ETS cap component by component. The cap is one jaw of a vice now closing on aviation: by making the right to emit progressively scarcer and dearer, it raises the cost of the fossil status quo. The second jaw is ReFuelEU Aviation, which from 2025 obliges fuel suppliers at EU airports to blend a rising share of SAF — 2 % in 2025, 6 % by 2030, 20 % by 2035 and 70 % by 2050 — with a dedicated synthetic (e-SAF) sub-mandate inside it. One instrument prices scarcity; the other manufactures demand.

The difficulty is that the demand is for a fuel that does not yet exist at anything like the required scale. Today's SAF is a rounding error against jet-fuel consumption, and most of it is made by a single mature route (HEFA) from a feedstock — waste oils and fats — that is already scarce and largely spoken for. Reaching the later mandate steps means standing up pathways that are still at first-of-a-kind stage, and building or massively upscaling the industrial systems they depend on: lignocellulosic gasification, alcohol fermentation, and above all the renewable electricity and hydrogen that power-to-liquid fuels require. This is industrial reconfiguration on a scale with few peacetime precedents, and it has to happen along a fixed regulatory timetable.

Our modelling tries to tackle the problem from both ends at once: from the supply side, by mapping the process network that converts feedstocks into fuel and costing the flows through it; and from the demand side, by translating the mandate trajectory into the volumes of SAF and e-SAF the system must deliver year by year. Where the two meet — where required volume runs into a binding feedstock, power or regulatory ceiling — is where prices move and where the investment case is made or broken. The ambition is modest in method and large in intent: to apply actuarial discipline, the explicit and reproducible quantification of uncertain future quantities, to decisions that are at present too often taken on the basis of brochures and optimism.

The remainder of this paper sets out the modelling approach (§2), reads the SAF pathways through a financial and economic lens (§3), presents the data exhibits and their sources (§4), describes the calculator and API that operationalise the model (§5), and closes with limitations, versioning and an invitation to cooperate (§6). The pathway flow diagrams are collected in Appendix A.

Sources. ReFuelEU Aviation Regulation (EU) 2023/2405; RED III (Directive (EU) 2023/2413); EU ETS as reconstructed in Working Paper 02 / 2026; Concawe Report 5/26 (EU transport demand to 2050).

2. APPROACH: A PRODUCER-AGNOSTIC PROCESS NETWORK

The model is a directed graph. Nodes are feedstocks, utilities, process steps, intermediates, co-products and final products; edges are flows between them, measured in tonnes for mass and in megawatt-hours for energy. Crucially it is producer-agnostic: it maps the system rather than any one company's plant, so that volumes reconcile across pathways and shared resources — hydrogen, power, refinery units — are visible as common nodes. The intent is to attach real volumes to the steps and from there model cost, availability, bottlenecks and price shocks under different scenarios.

Three properties make the network usable as an analytical engine rather than a picture. First, it is mass-balanced: at every process node, mass in equals mass out, verified in code for all pathways. Second, it is table-driven: the nodes, edges and per-scenario flows live in a small set of canonical tables that are the single source of truth, from which the diagrams and the calculations are both generated — so the two can never drift apart. Third, it is scenario-filtered: each pathway is a sub-graph of one master network, drawn and costed on its own but reconciling with the rest.

A single operating assumption is imposed throughout: the producer maximises the SAF (jet) fraction, because aviation is the hardest transport mode to electrify and SAF carries the largest premium and the binding mandate, and values the residual product slate — naphtha, diesel, LPG, protein meal — at current market prices, crediting that revenue against the cost of the SAF. This is a deliberate, transparent policy choice, not a hidden optimisation, and it can be varied.

Because the network is linear and balanced, it inverts cleanly. The forward model says how much fuel a given feedstock yields; the calculator runs it backwards — given a target SAF volume and type, it scales the whole flow vector by a single factor and reports the inputs required, the residuals of those inputs, the saleable side-products, and the caps the requested volume approaches. This inverse is the basis of the service described in §5. Every result is stamped with a code version and a data version so any figure cited from it is reproducible.

Sources. Own model (this thread); methodology consistent with mass-balance process-network and well-to-tank conventions (JEC/JRC; GREET).

3. THE PATHWAYS THROUGH A FINANCIAL–ECONOMIC LENS

What follows is deliberately not an engineering account. The chemistry matters only insofar as it sets the quantities — how much feedstock, power and hydrogen a tonne of SAF needs, and what else comes out of the process — because those quantities are what drive cost, scalability and competition for resources. Six routes are modelled — co-processing, two HEFA variants, Fischer–Tropsch, alcohol-to-jet, and power-to-liquid — the principal certified pathways at or near commercial scale. Emerging routes (algae-based HEFA, synthesised iso-paraffins and other early ASTM annexes) are acknowledged but not yet quantified.

3.1 The routes and where they sit in the industrial system

Co-processing feeds a modest share of bio-oil into an existing oil refinery's hydrotreater. It is the cheapest and fastest route precisely because it builds almost nothing new — but the co-feed share is capped for technical and certification reasons, so it can only ever be a partial answer.

HEFA hydrotreats waste oils and fats into renewable jet and diesel. It is the only mature, at-scale route and the cheapest to build as a standalone, but it is boxed in by feedstock: used cooking oil and animal fats are an Annex IX Part B feedstock under RED III (Directive (EU) 2023/2413) — eligible but capped at 1.7 % of transport energy — and the obvious alternative, virgin vegetable oils from food crops, is excluded from the SAF mandate altogether. The oilseed variant in the model illustrates why the familiar "food versus fuel" framing is too blunt: only about a third of an oilseed becomes oil for fuel, while the bulk leaves as protein-rich meal that still feeds livestock. The same crop yields both a fuel and a food-chain output, so the route is as much a feed business as a fuel one — and charging its entire land and carbon footprint to the fuel misrepresents it. That is the allocation question raised in §2, and a reason to treat blanket "crop-based biofuel" judgements with care.

Fischer–Tropsch (BtL) gasifies lignocellulosic residues and waste to syngas and synthesises liquids. The feedstock is advanced and abundant relative to oils and fats, but the route is entirely new build, capital-heavy, and converts only about a fifth of dry biomass mass into liquid fuel — so feedstock logistics and scale dominate.

Alcohol-to-jet dehydrates and upgrades ethanol into jet. Its economics turn on the ethanol: crop ethanol is excluded from the mandate, so the eligible versions rely on cellulosic or waste-gas-derived ethanol (the LanzaTech route), whose supply is itself still scaling.

Power-to-liquid (e-SAF) makes fuel from captured CO_2 and green hydrogen. It is the route the synthetic sub-mandate is written for and the one furthest from scale: it needs vast quantities of new renewable electricity and electrolysis, and essentially builds a chemical plant and a power station to make a barrel of kerosene. Of all the routes it depends most on industrial systems that do not yet exist at the required size.

Read together, the routes form a ladder from "use what exists" (co-processing, HEFA) to "build an entire new system" (FT, e-SAF). The mandate's shape — modest early, steep later, with a synthetic carve-out — effectively forces movement up that ladder over time, which is why the binding constraint migrates from feedstock to power as the years pass.

3.2 Cross-industry interactions and competition for resources

None of these pathways sits in isolation, and this is central to the analysis. On the output side, every route throws off co-products that belong to other markets: renewable diesel and naphtha into road and petrochemicals, protein meal into animal feed, oxygen into industry. These are not waste; their value materially offsets the cost of the SAF, and ignoring them overstates the true cost of jet. On the input side, the same feedstocks and utilities are contested: waste oils and fats are also wanted by road biodiesel; lignocellulosic biomass is also wanted for power, heat and materials; and renewable electricity and hydrogen are wanted by every decarbonising sector at once. SAF does not get to draw on these pools uncontested — it competes, and the price it pays is set in those wider markets.

This is the circular-economy core of the modelling: a pathway can only be costed honestly if the whole system around it is accounted for, on both the output and the input side. A tonne of SAF that also yields a tonne of animal feed, and that bids for power against data centres and steel, has an economic profile that no plant-level engineering yield can capture on its own.

3.3 The economics: break-evens and what drives them

It helps to be explicit about which costs are in view, since the audience is a financial one. Our model computes a variable cash cost per tonne of SAF — feedstock plus energy, that is, the variable OPEX — under the maximise-SAF policy with co-products credited at current prices (Exhibit 1). It deliberately excludes fixed operating costs and capital recovery (CAPEX), so it is a floor, not a full cost. On this variable-OPEX basis the pattern is clear: Fischer–Tropsch is lowest, because lignocellulosic residues are cheap — which flatters the route that is in fact the most capital-intensive to build. Alcohol-to-jet and HEFA sit in the middle, helped by valuable co-products. Power-to-liquid sits far above the rest and above the SAF price itself: even on variable OPEX alone, dominated by electricity and hydrogen, it does not currently cover its cash costs at prevailing power prices.

The other bracket — full cost, including fixed OPEX and CAPEX — is now available from an authoritative source. EASA publishes annual reference prices for ReFuelEU-eligible fuels: market index prices where a market exists, and production-cost estimates (feedstock, energy, OPEX and CAPEX) where it does not. The 2025 figures (Exhibit 2) are stark. Conventional jet is €640 per tonne; HEFA biofuel trades at about €1,925; advanced biofuel is estimated at €2,760; and synthetic e-SAF averages €7,520, rising to €8,625 for the direct-air-capture variant — roughly twelve times conventional jet. Set against our variable-OPEX floor for e-SAF (about $3,276), EASA's full cost implies that fixed operating and capital costs more than double the number: e-SAF is dear not mainly because of feedstock but because of energy and capital together. (The two bases differ — EASA quotes €/tonne of product, not energy-adjusted; ours is a $/tonne variable-cost floor — so the comparison is indicative of magnitude, not exact.)

This is the e-SAF viability gap in official numbers, and it has a sharp market consequence. Where a mandated fuel is unavailable, the binding price is not its production cost but the cost of non-compliance — the buy-out — toward which a short market will tend; one airline analysis puts the implied 2030 e-SAF premium in a tight Scandinavian market as high as €23,000 per tonne. The investment problem is therefore less about unit economics than about bankability: developers report spending up to €50 million per project before a final investment decision, against a cost stack dominated by capital and the cost of capital. These are the numbers a financial reader needs, and they reframe the question from price to whether the capacity is built at all.

3.4 Constraints, caps and the supply–demand gap

The mandate sets the demand; the resource system sets the supply; the gap between them is where the action is. On the supply side the binding ceilings are, in order of how soon they bite: the RED III (Directive (EU) 2023/2413) Annex IX Part B cap on used cooking oil and animal fats; the exclusion of food and feed crops; the sustainable availability of lignocellulosic biomass; and, for e-SAF, the build-out of renewable electricity. On the demand side, translating the ReFuelEU percentages onto EU aviation jet demand gives the required SAF and e-SAF volumes year by year (Exhibit 3).

Crossing the two (Exhibits 3 and 4) shows the shape of the problem. Required SAF volume by 2050 is a large fraction of the entire EU sustainable advanced-and-waste biofuel supply — so aviation is not a marginal claimant on biomass but a dominant one, in direct competition with road, shipping and the chemical industry. And the synthetic sub-mandate runs straight into the renewable-power ceiling: the e-SAF volumes implied for the 2040s require quantities of additional renewable electricity that are large even against the current record pace of build-out. The gap is not uniform — it is widest, soonest, for e-SAF — which is exactly where policy and investment attention are least matched to physical reality.

Sources. Pathway data: Altalto/Velocys, Sustainable Molecules (SuMo)/SUEZ/Velocys/COX, NEXTGEN-SAF (Univ. Sheffield/E.ON), LanzaTech DRAGON II, Zero Petroleum (SAF Café decks). Yields & energy: Concawe Report 17/22 (e-fuels TEA); IEA Bioenergy Task 39; published BtL/HEFA/ATJ literature (GREET/JEC to confirm). Feedstock & power: Concawe biomass-availability studies; JRC biomass reports (JRC133505/140117); IRENA Renewable Capacity Statistics 2026; IRENA Green Hydrogen Cost (2020). Demand: Concawe Report 5/26. Costs (full OPEX+CAPEX): EASA 2025 reference prices (methodology + 2026 briefing). The e-SAF viability gap: The eFuels Gap (SAF Congress); SAS, The need for e-SAF in Scandinavia; CE Delft, Sustainable carbon for aviation & shipping (2025). Regulation: ReFuelEU (EU) 2023/2405; RED III (EU) 2023/2413.

3.5 The carbon bottleneck for e-SAF

Power is the headline e-SAF constraint, but it has a quieter twin: carbon. Every tonne of e-SAF is built on captured CO_2 — roughly six tonnes of it per tonne of fuel in our power-to-liquid case — so the synthetic sub-mandate is implicitly also a mandate to capture and purify very large volumes of CO_2. And not just any CO_2.

Eligibility narrows the pool sharply. Under the RFNBO rules, e-SAF qualifies when its carbon comes from the atmosphere (direct air capture) or from qualifying non-fossil sources; carbon taken from fossil point sources is being phased out as an eligible input, and biogenic CO_2 released by combustion or gasification tends to classify the resulting fuel as a biofuel rather than a renewable fuel of non-biological origin — so it does not count toward the synthetic target. The cheap, abundant CO_2 — a cement flue or a power-station stack — is largely the wrong CO_2 for the fuel the mandate most wants.

What remains is contested and, today, dear. CE Delft estimates that demand for sustainable carbon from aviation, shipping and other sectors may exceed its availability well before 2050, with aviation e-fuels alone needing carbon on the order of single-digit megatonnes a year. Direct air capture is the eligibility-safe source but is energy-intensive and costly — which compounds the power bottleneck, since capturing the carbon itself consumes renewable electricity. The carbon constraint and the power constraint are therefore not independent: DAC-based e-SAF pays the energy price twice.

This is where emerging capture routes matter, and where contacts such as Pure Carbon Blue fit the picture. Its direct water capture extracts CO_2 from water — where carbon is around a hundred times more concentrated than in air — at an estimated $100–250 per tonne, materially below typical DAC costs, with a first pilot at demonstration readiness. If routes like this scale, they widen the supply of eligibility-friendly, affordable CO_2 and ease one jaw of the e-SAF squeeze; if they do not, the carbon bottleneck binds alongside power. The model treats CO_2 as a single input today; the natural next step is to split it by source — fossil point-source, biogenic, DAC and direct water capture — each carrying its own eligibility, cost and energy burden (Exhibit 5).

Sources. CE Delft, Sustainable carbon for aviation and shipping (2025); RED III RFNBO rules on eligible CO_2; Pure Carbon Blue (purecarbon.blue) — direct water capture, company materials and press (2026; TRL ~5; ~$100–250/t CO_2).

4. DATA EXHIBITS

EXHIBIT 1 SAF pathways — basis, SAF yield, principal co-products, and break-even. Break-even here is a variable cash cost (feedstock + energy = variable OPEX), under the maximise-SAF policy with co-products credited at current indicative prices; it excludes fixed OPEX and capital recovery (CAPEX) and downstream blending. For the full-cost bracket (OPEX + CAPEX) see Exhibit 2. Indicative, model data version v0.3.0.

Pathway (ASTM)	Basis	SAF yield	Principal co-products	Break-even ($/t SAF)*	Key source anchors
Co-processing (D1655)	100 t crude + 5 t bio-oil	21.5 t jet	refinery slate (shared)	~833	S. Van Dyk course
HEFA (D7566 A2)	100 t oils & fats	50 t	renewable diesel, naphtha, propane	~1,878	GREET (~0.8 t paraffin/t oil); HEFA lit.
HEFA — oilseed (A2)	100 t oilseed	15 t	65 t protein meal; r-diesel, naphtha	~2,262	S. Van Dyk (oil/meal split)
Fischer–Tropsch (A1)	100 t dry biomass	14 t	FT naphtha, diesel, LPG	~814	Altalto; SuMo; NEXTGEN; BtL lit.
Alcohol-to-Jet (A5)	100 t ethanol	53 t	renewable diesel, naphtha, LPG	~1,345	LanzaTech DRAGON II
Power-to-Liquid (A1, RFNBO)	100 t CO_2 + 14.6 t green H_2 (~805 MWh)	17 t	e-naphtha, e-diesel, O_2	~3,276	Concawe 17/22; Zero; IRENA

Reference SAF market price ≈ $2,600/t (HEFA-SPK, mid-2026). A variable-cost break-even below it means feedstock and energy are covered before fixed OPEX and capital; e-SAF's variable cost alone already exceeds it.

EXHIBIT 2 EASA 2025 reference prices for ReFuelEU-eligible aviation fuels (€/tonne of product, not energy-adjusted). 'Real index' = market price where a market exists; 'production-cost estimate' = feedstock + energy + OPEX + CAPEX where it does not. These are full costs — the upper bracket to the variable-OPEX floor in Exhibit 1.

RFEUA fuel subcategory	Real index (market) €/t	Production cost (incl. CAPEX) €/t	Note
Conventional jet (fossil)	640	—	fossil benchmark
Aviation biofuel (HEFA, Annex IX B)	1,925	1,630	market-traded
Advanced aviation biofuel	—	2,760 [1,790–3,130]	FT / ATJ etc.
Recycled-carbon aviation fuel	—	2,195 [1,805–2,540]	e.g. waste-gas
Synthetic e-SAF (weighted avg)	—	7,520 [6,710–9,525]	RFNBO; ~12× jet
e-SAF from atmospheric CO_2 (DAC)	—	8,625 [7,815–9,525]	most expensive
Renewable hydrogen for aviation	—	7,705 [6,810–8,700]	direct H_2 use

Source. EASA, 2025 Aviation Fuels Reference Prices for ReFuelEU Aviation (briefing note, 2026) and the EASA reference-price methodology (OPEX §4.2.1, CAPEX §4.2.2).

EXHIBIT 3 EU aviation jet demand × ReFuelEU mandates → required SAF and e-SAF (Mtoe). Demand 48.3 Mtoe in 2019 growing to 57–87 Mtoe by 2050 (low–high). Reproduces Concawe's own 2050 split as a check.

Year	Jet demand low–high (Mtoe)	SAF mandate	Synthetic	Req. SAF low–high (Mtoe)	Req. e-SAF low–high (Mtoe)
2025	49.0	2 %	—	1.0	—
2030	51.8	6 %	1.2 %	3.1	0.6
2035	53.1 – 58.9	20 %	5 %	10.6 – 11.8	2.7 – 3.0
2040	54.5 – 66.9	34 %	10 %	18.5 – 22.7	5.4 – 6.7
2050	57.4 – 86.6	70 %	35 %	40.2 – 60.6	20.1 – 30.3

Source. Concawe Report 5/26 (demand); ReFuelEU (EU) 2023/2405 (mandate %).

EXHIBIT 4 EU feedstock and power ceilings the routes draw on (the supply side of the gap).

Resource	Scope / metric	Availability	Cap / note
All Annex IX A&B biomass	Advanced + waste biofuel output, EU27+UK	46–97 Mtoe (2030); 71–176 (2050)	Aviation SAF demand is a large share of this
Lignocellulosic (FT)	Sustainable potential	124–181 Mtoe (2030); 134–199 (2050)	Competes with power, heat, materials
UCO + animal fats (HEFA)	Annex IX Part B	scarce; partly to road biodiesel	Capped at 1.7 % of transport energy
Oilseed / crop ethanol	Food/feed crops	large but ineligible	Excluded from / capped in SAF share
Renewable power (e-SAF)	Build-out	+692 GW added globally in 2025	RFNBO additionality; binding e-SAF limit
CO_2 (e-SAF)	Point-source / DAC	industrial / biogenic sources	Not biomass; DAC is energy-intensive

Source. Concawe biomass-availability studies; JRC133505/140117; IRENA Renewable Capacity Statistics 2026.

EXHIBIT 5 CO_2 sources for e-SAF — eligibility, indicative cost and the bottleneck. e-SAF needs ~6 t CO_2 per t fuel; eligibility and cost, not raw CO_2 abundance, are the binding factors.

CO_2 source	RFNBO eligibility	Indicative cost (€/t CO_2)	Note
Fossil point-source (cement, power)	Being phased out as eligible	low (~30–60)	abundant but not RFNBO-durable
Biogenic point-source (combustion / gasification)	Often makes the fuel a biofuel, not RFNBO	low–medium	rules-limited for the synthetic target
Direct air capture (DAC)	Eligible (atmospheric)	high; energy-intensive	eligibility-safe but costly; adds to the power burden
Direct water capture (Pure Carbon Blue)	Atmospheric origin	~$100–250 (≈ €90–230)	TRL ~5; potentially well below DAC

Source. RED III RFNBO criteria; CE Delft (2025); Pure Carbon Blue. Costs indicative; the model's single CO_2 input is to be split along these lines.

5. THE CALCULATOR AND THE API

The model is operationalised as a calculation module that inverts the network. The free online version is at peterkeutgens.com/tools/saf-calculator/. Given a SAF type and a target tonnage (with an optional mandate year, defaulting to 2030), the calculator returns the inputs required to deliver the requested volume, the residuals of those inputs, the saleable side-products that accompany the SAF, and a set of traffic lights flagging the feedstock, power and regulatory ceilings the request approaches. The pathway flow diagram is annotated with the per-request quantities on the SAF output node, so the picture on screen and the numbers in the tables are produced from the same scaled flow vector.

A worked example. 100,000 t/yr of HEFA SAF requires about 200,000 t of oils and fats and 11,000 t of hydrogen; yields about 40,000 t of renewable diesel and 24,000 t of naphtha alongside the jet; and represents roughly 3.2 % of the EU SAF mandate in 2030 — with the feedstock flagged amber for the Annex IX Part B cap. The other pathways return the same shape of answer with different streams: Fischer–Tropsch reads as a biomass-and-hydrogen-heavy regime with naphtha, diesel and LPG side-products; alcohol-to-jet turns on ethanol supply; power-to-liquid carries the two-axis input split that the route demands, mass-unit CO_2 and hydrogen alongside megawatt-hour-unit renewable electricity.

Every result carries the engine and data versions that produced it, displayed on screen and reproduced in the PDF copy a reader can request by email. Quoting a figure from the calculator therefore traces back to a specific model state. The data version that backs the figures in this paper (v0.3.0, 11 June 2026) is the same version the calculator returns by default; later data versions will be visible in the version stamp on each result without changing the calculator's interface, so the reproducibility of any cited figure does not depend on the paper itself being re-issued.

The interface returns derived analytics — computed quantities, ratios and traffic lights — and not the underlying parameter tables or any direct access to them. This is deliberate: the service is meant to operationalise the model for analytical use, not to substitute for the data providers whose work it draws on. The HTTP API behind the on-screen tool follows the OpenAPI specification at `api.peterkeutgens.com/openapi.json`. Direct programmatic access is available on request and requires an API key.

6. LIMITATIONS, VERSIONING AND AN INVITATION TO COOPERATE

This is a working draft and should be read as one. The quantities are indicative and public-source-derived; the production boundary stops at neat SPK, so blending and capital cost are excluded; the internal split of the Fischer–Tropsch train is illustrative; the bio-route mass yields are corroborated from the literature but await confirmation against the GREET and JEC well-to-tank datasets; and the geographic focus is the EU, while some of the markets involved are global. Each of these is a known edge of the model, named so that it can be argued with.

Every figure in this paper is reproducible. The model carries two version stamps — the code (engine) version and the data version — and the figures and exhibits regenerate from the canonical tables, so any number quoted here can be traced to an exact model state. This draft is built on data version v0.3.0 (2026-06-11).

Above all this paper is an invitation to cooperate, not a finished product. The system it describes is being built now, by the companies whose disclosures and presentations underpin much of the data here, and the model will only be as good as the scrutiny it survives. I would welcome correction and contribution — on yields, energy and hydrogen intensities, real plant capacities, feedstock availabilities and the assumptions behind them — from the SAF Café network and from the named developers and researchers cited throughout. The point of making the assumptions explicit and the sources named is precisely to make that conversation possible.

Sources. All sources are collected in the data register that travels with the model.

REFERENCES

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Feedstock, biomass and power. Concawe, Sustainable biomass availability in the EU to 2050 (Annex IX A&B); JRC, Biomass supply and uses in the EU (JRC133505, 2023; JRC140117, 2025); JRC142012, Updating GHG default values (RED II Annex V & VI, 2026); IRENA, Renewable Capacity Statistics 2026 and Renewable Energy Statistics 2025.

A complete, machine-readable register with coverage notes is maintained in the model's data sources register.

APPENDIX A · PATHWAY FLOW DIAGRAMS

Each diagram is generated automatically from the same model tables as the exhibits (mass in tonnes, balanced; energy in MWh). The jet/SAF spine is shown in green, the SAF product node bold-bordered; colour coding per the legend below. These pages are A3 landscape and the figures are vector — best viewed on screen (zoomable) or printed on A3.

Legend

Legend	
	Feedstock (fossil/crop)
	Bio-feedstock
	e-Feedstock (CO_2 / water)
	Utility (H_2, O_2, power)
	Process step
	Intermediate
	Co-product / residual
	Final product (Jet A-1)
— jet (SAF) spine	— e-fuel carbon
---- energy (MWh)	---- H_2 bold border = SAF product

Exhibit A1 · Fossil Jet A-1 baseline (S1)

The reference point: conventional jet from crude oil. Shown for comparison; this is what SAF displaces.

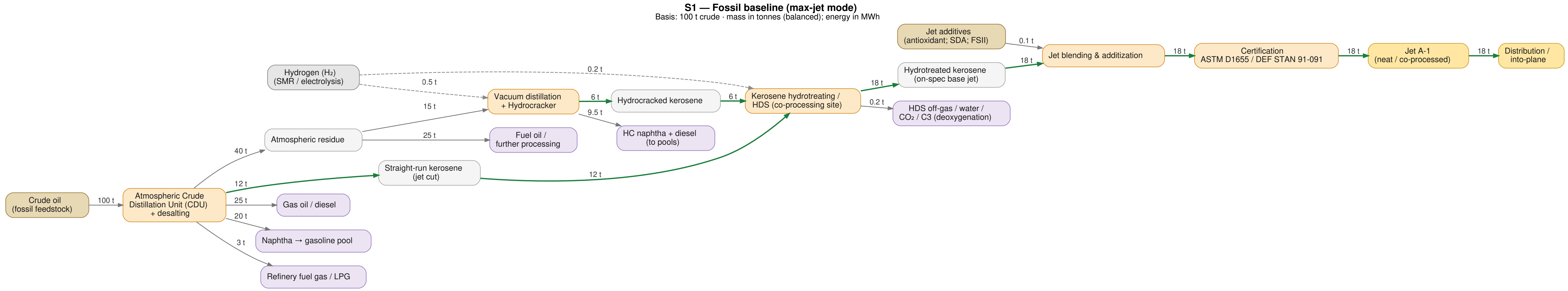

Exhibit A2 · Co-processing of oils & fats (S2)

A small share of bio-oil co-fed into an existing oil refinery's hydrotreater. Cheapest and fastest because it builds almost nothing new; capped by certification.

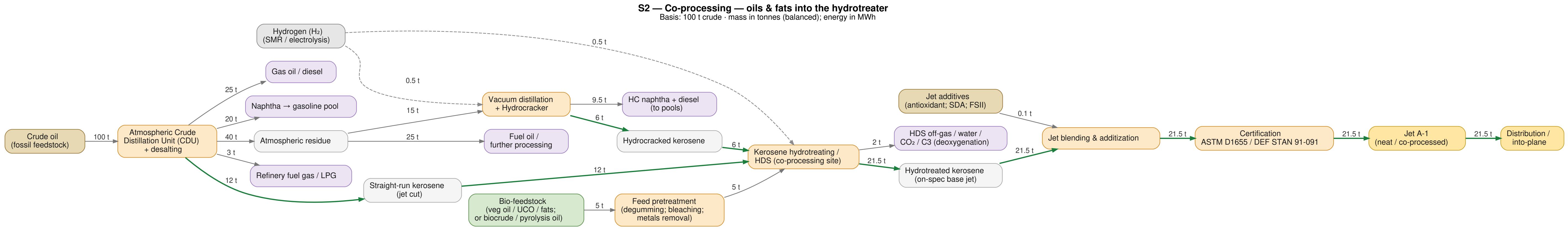

Exhibit A3 · HEFA-SPK (H1)

Hydroprocessed esters and fatty acids. The only mature, at-scale SAF route today; feedstock-bound by the Annex IX Part B cap on used cooking oil and animal fats.

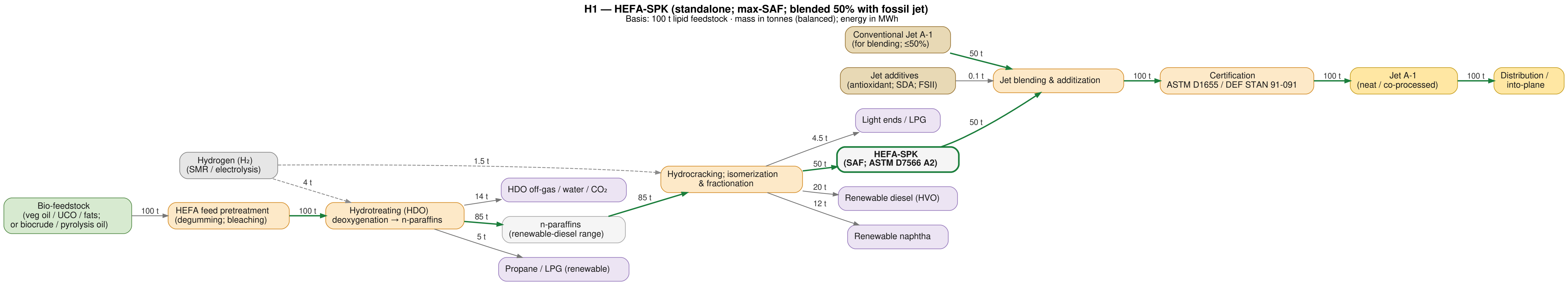

Exhibit A4 · Fischer–Tropsch / BtL (F1)

Gasification of lignocellulosic residues and waste to syngas, then synthesis to liquids. Advanced and abundant feedstock; entirely new build; capital-heavy.

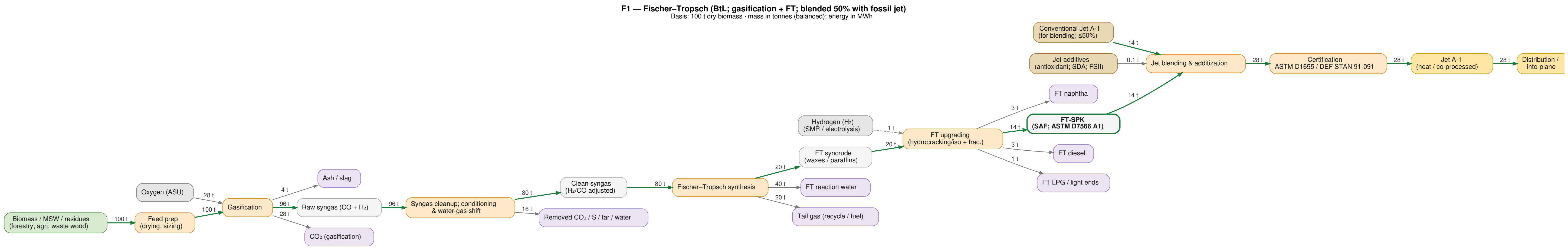

Exhibit A5 · Alcohol-to-Jet (A1)

Ethanol — cellulosic or waste-gas derived, since crop ethanol is excluded — dehydrated and upgraded into jet. Economics turn on ethanol supply.

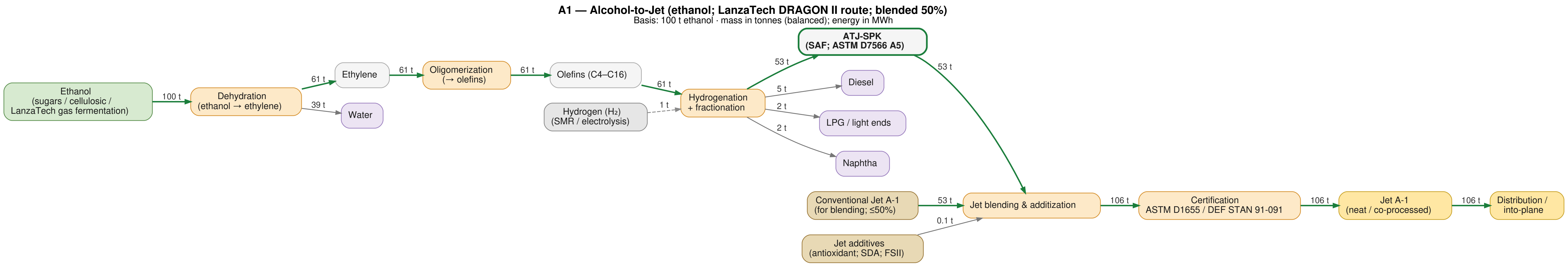

Exhibit A6 · Power-to-Liquid / e-SAF (E1)

Captured CO_2 plus green hydrogen synthesised to kerosene. The route the synthetic sub-mandate is written for; furthest from scale; dependent on renewable electricity and electrolysis at sizes that do not yet exist.

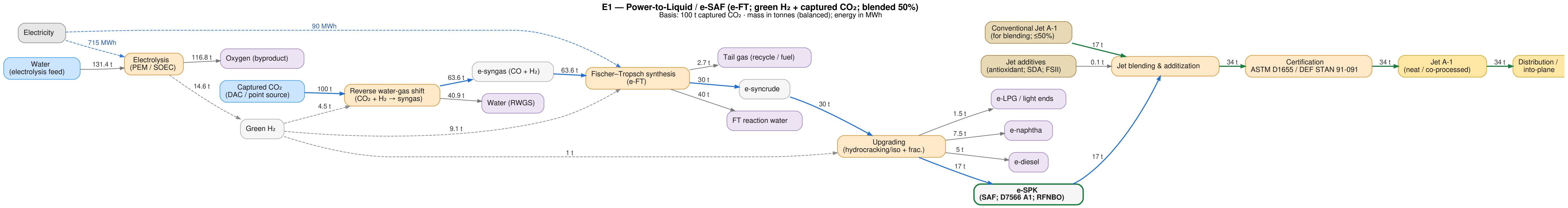

Exhibit A7 · HEFA from oilseed, with protein-meal co-product (H2)

Oilseed crushed to oil and meal; only the oil is hydrotreated to SAF, the bulk leaves as protein meal that feeds livestock. Illustrates why "food versus fuel" is too blunt for routes that yield both.