Decarbonising Europe's refining and liquid fuel production — insights from the Concawe-S&P Global study

This article presents a technical synthesis of an S&P Global Commodity Insights study commissioned by Concawe on the evolution of Europe's refining and liquid fuel manufacturing sectors to 2050. Two illustrative net-zero pathways are assessed: 'Max Electron', characterised by accelerated electrification, and 'More Molecule', which places greater emphasis on low-carbon fuels. Both pathways indicate a substantial decline in fossil fuel demand and refining capacity, alongside significant growth in biofuels, hydrogen and e-fuels, requiring coordinated policy support and investment.

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Introduction

Europe's 2050 climate neutrality ambition is inducing a profound transformation of the petroleum refining and renewable fuel manufacturing sectors. This article summarises key findings from the S&P Global Commodity Insights (SPGCI) study[1] commissioned by Concawe to assess the potential evolution of refining and liquid fuel production in Europe to 2050 under two pathways achieving the European Union's (EU's) 2050 net-zero greenhouse gas (GHG) emissions target through contrasting technology and energy-system strategies.

Concawe has already studied opportunities and challenges with regard to the future of the EU refining industry amid the ongoing transition to a low CO_2-intensive economy up to 2030 and 2050, and published different scenarios, including considering an increase in the production of low-carbon fuels, such as sustainable biofuels and e-fuels, in its 'Refinery 2050' report.[2]

The objective of this study is to assist stakeholders to better understand the possible impact on the refining industry of two different scenarios, regarding mobility and energy supply, meeting the net-zero greenhouse gas emission target in 2050 with segregation by clusters of European states.

This will provide European states with a deeper understanding of the impacts of different ways to achieve climate neutrality on their economies and on the security of supply of fuels and other refinery products of key importance for the economic value chain of EU-27 + 3 states.[1] It also addresses potential fuel supply issues that could impact fuel security during the energy transition phase.

Context and methodology

EU legislation review

The European Green Deal,[2] presented by the European Commission in December 2019, is a set of policy measures aimed at promoting environmentally sustainable development and economic growth across the EU with the overarching goal of achieving climate neutrality by 2050. It covers all sectors of the economy, including transport, energy, agriculture and industry, with actionable policies aimed at reducing emissions and promoting energy transition.

The European Climate Law[3] transforms the European Green Deal's political commitment into a legal obligation and details the necessary steps to get there. EU Member States and the European Parliament approved the European Climate Law on 29 July 2021. By adopting it, the EU and its Member States committed to the intermediate target of cutting net GHG emissions in the EU by at least 55% by 2030, compared with 1990 levels. This 55% reduction is covered by the Fit for 55 package,[4] proposed in July 2021.

1 The 27 member countries of the European Union, plus Norway, Switzerland and the UK (also 'EU+')

2 European Green Deal

3 European Climate Law

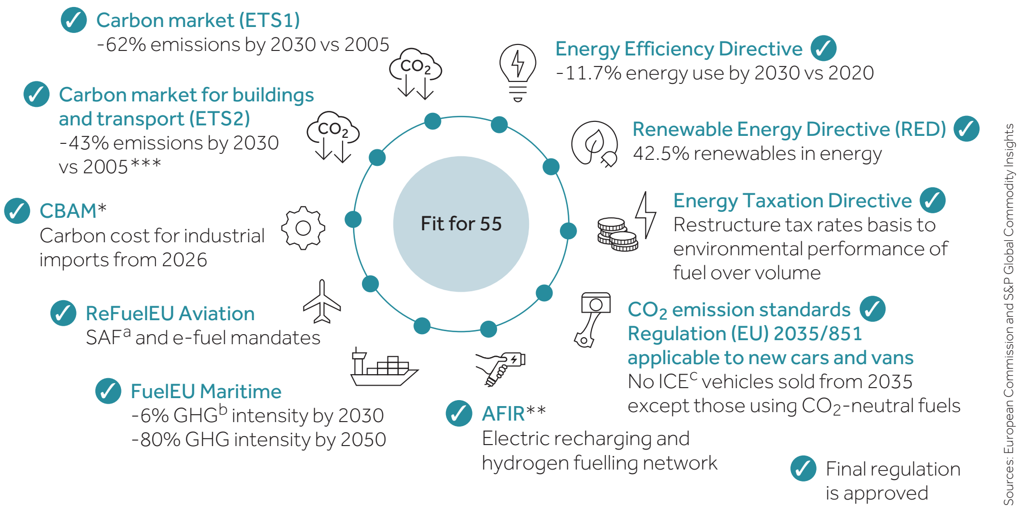
4 'Fit for 55: Delivering on the proposals' (online).

European policy framework

The transformation takes place within a demanding regulatory landscape shaped by the European Green Deal, Fit for 55 package (see Figure 1) and Renewable Energy Directive III (RED III).

These measures accelerate decarbonisation across transport, power and industry. Carbon prices are assumed to rise steadily, reaching EUR 350–400/t CO_2 by 2050.

Figure 1: Fit for 55 policy initiatives



[a] SAF = sustainable aviation fuel [b] GHG = greenhouse gas [c] ICE = internal combustion engine

* CBAM: carbon border adjustment mechanism

** AFIR: alternative fuels infrastructure regulation

*** The release for consumption of fuels for which the emission factor is zero is not considered in the scope of ETS and ETS2. Under the ETS Monitoring and Reporting Regulation (MRR), the zero rating applies to renewable fuels compliant with the RED (biofuels, RFNBOs and recycled carbon fuels (RCFs)), as well as low-carbon fuels defined in Article 2 (13) of the EU Gas Directive (Directive (EU) 2024/1788) and certified according to the provisions set by Article 9.

Scenario modelling by SPGCI

The Energy and Climate Scenarios are typically used by clients of SPGCI for creating and testing their strategy. SPGCI's Green Rules scenario represents the current view of the fastest plausible energy transition, but it is not net zero globally, and results in a global temperature rise of +1.7°C by 2100. Green Rules is, however, essentially net zero when looking at Europe by 2050.

For this study, S&P Global created two bespoke scenarios — 'Max Electron' and 'More Molecule'. Both used the Green Rules scenario from the SPGCI Energy and Climate Scenario service as a starting point.

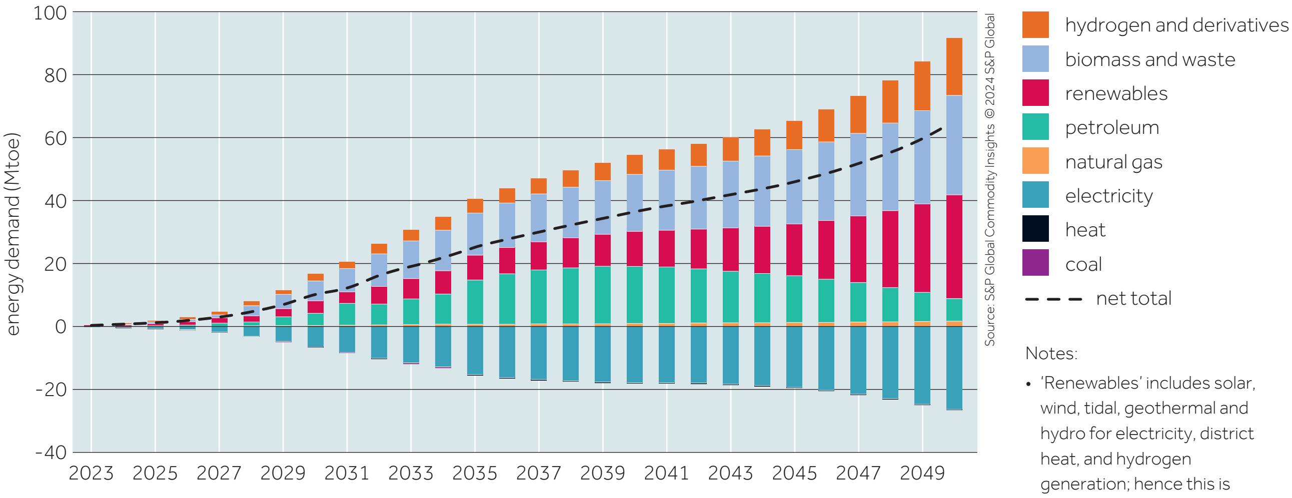
The first, the Max Electron scenario, meets all requirements of the Fit for 55 package while surpassing the requirements of the EU's CO_2 standards regulation for HDVs[5] by assuming zero sales of ICE vehicles after 2035. It assumes an accelerated and unprecedented rate of electrification across various modes of transportation, with widespread use of renewable electricity, heat pumps and hydrogen.

The second, the More Molecule scenario, was derived from the Max Electron scenario by relaxing the requirements of the LDV and HDV vehicle standards and allowing sales of some new internal combustion engine cars and vans after 2035, and postponing any electrification in the aviation and marine sectors until after 2050. This scenario achieves net zero in 2050 by complementing electrification with an increased use of low-carbon and renewable fuels, relying more heavily on biofuels and RFNBOs.

Both scenarios rely on an important shift of road and aviation transport to rail. The increase in rail activity required to meet the net-zero emission objective in 2050 represents a major challenge, which will require significant investment in the rail infrastructure. Both pathways were built using the S&P Global Integrated Energy Model and detailed refinery-level LP modelling.

Comparing the overall total energy demand for the More Molecule and More Electron scenarios by 2050, the More Molecule scenario requires 65 Mtoe more energy demand as compared to the Max Electron scenario by 2050 (see Figure 2).

Figure 2: Delta total energy demand outlook: More Molecule minus Max Electron (Mtoe)
(for the EU-27 plus Norway, Switzerland and the UK)



Notes:
- 'Renewables' includes solar, wind, tidal, geothermal and hydro for electricity, district heat, and hydrogen generation; hence this is renewables input to the production of electricity, heat and hydrogen/hydrogen derivatives.
- Values greater than zero reflect a greater demand in the More Molecule scenario compared to the Max Electron scenario.

[5] Regulation (EU) 2024/1610

Linear programming analysis

The Max Electron and More Molecule scenarios present a significant modification in the EU+ region's refinery landscape, driven by S&P Global's proprietary forecast of industrial and transport activity, by the adoption of e-mobility, and by the transition to low-carbon fuels. These transformations are poised to reshape liquid fuel demand, traditional refining capacities and product balances, necessitating strategic adaptations from the refining industry, and its transition to low-carbon fuels manufacturing.

S&P Global developed a linear program (LP) model, in which all EU+ refineries are represented.

The declining local market demand for fossil products impacts conventional refinery viability, with LP model outputs showing increasing numbers of EU+ refineries projected to have negative margins over time under both scenarios. Refineries showing negative margins in 2024, 2030, 2040 and 2050 are deemed to stop operations.

Existing refineries will have to align their capacities with lower margins resulting from decreasing market demand for fossil fuels. Conventional refining capacity is projected to decrease from 13 Mbbl/d in 2024 to 2.1 Mbbl/day in More Molecule and 1.7 Mbbl/day in Max Electron by 2050. This significant reduction reflects the negative margins due to the declining fossil fuels demand and the corresponding need for refineries to adjust their operations to match market dynamics.

Figure 3: Numbers of refineries remaining in 2024, 2030, 2040 and 2050 in the Max Electron and More Molecule scenarios

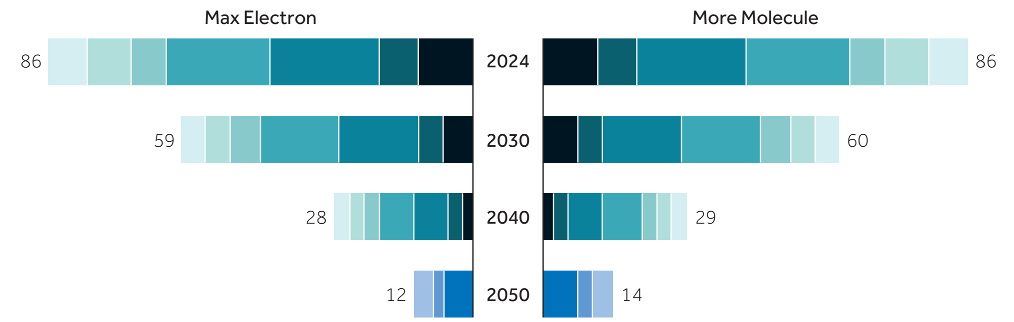
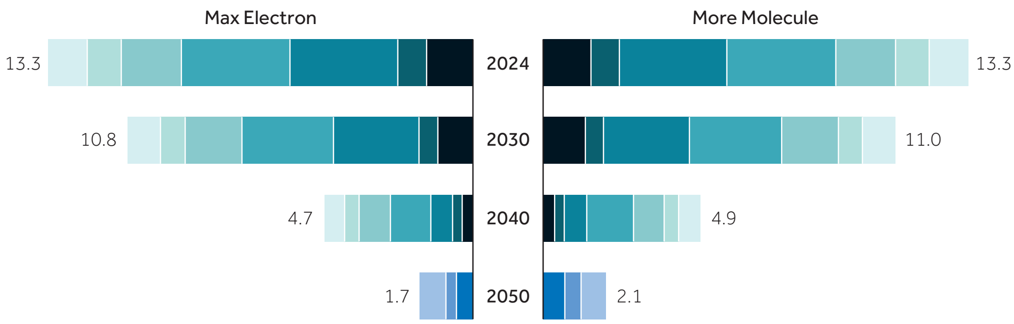


Figure 4: Refining capacities remaining in 2024, 2030, 2040 and 2050 in the Max Electron and More Molecule scenarios (million barrels of oil per day)



In both cases, significant conventional refinery closures are expected. However, the demand for low-carbon fuels is higher in the More Molecule scenario, which creates greater opportunity for traditional refineries to be transformed to produce low-carbon fuels rather than being fully closed in this scenario.

Supply and demand

In both scenarios, EU+ demand for conventional hydrocarbons falls and the region enters a sustained period of having an excess of crude oil refining capacity. However, expected poor refining economics restricts the operating rate of conventional refineries and, as a result, refining cover for most fuels reduces over the period from 2024 to 2040. The demand for renewable liquid fuels increases, which provides some refineries with the opportunity to integrate more renewable feedstocks in the replacement of petroleum, and to transition to bio- or e-refineries.

Food and feed crop-based biofuels production capacity will enter long-term decline in line with falling fuel demand regardless of the scenario. Furthermore, it will fall to zero by 2050 to meet net-zero emissions because of the higher embedded CO_2 content of food and feed crop-based biofuels. RED Annex IX, Part B biofuels production capacity will also decline in line with falling fuel demand; in 2050, production is 5.2 Mtoe in Max Electron and 5.7 Mtoe in More Molecule.

In both scenarios, production capacity for Annex IX, Part A biofuels needs to increase in the long term to meet the rising demand for advanced biofuels. By 2050, in the Max Electron scenario, production capacity needs to rise to ±57 Mtoe, and to ±88 Mtoe in the More Molecule scenario.

A 2021 study on sustainable biomass availability in the EU, undertaken by Imperial College London at the request of Concawe, showed that the potential availability of advanced and waste-based biofuels (through EU domestic production) in 2050 can reach 137 Mtoe with some progress in biomass collection and research and development in yield improvement.[3] The demand for biofuels in the Max Electron scenario falls within the low to middle of sustainable biofuel potential availability, whereas the More Molecule scenario approaches the upper range of this estimate. This implies that improvement measures detailed in the Imperial College London study will be required to realise the higher mobilisation of biomass required.

SPGCI maintains a database of fatty acid methyl esters (FAME) plants, fuel ethanol plants and biorefineries which is updated by the SPGCI Biofuels Value Chain Service (BVCS) team of researchers and analysts. This database records global biofuel plants that are operating, and the projects that have been announced publicly by companies in the industry up to 2030. Collectively between the FAME plants, fuel ethanol plants and biorefineries—considering both current operational capacity and firm projects—EU+ biofuel production capacity is forecast at 33 Mtoe in 2030. It is assumed that two-thirds of this capacity could remain operational in 2040 and 2050.

As fossil fuel demand reduces, the use of spare capacity in the remaining refining infrastructure provides a useful path for producing biofuels. Our analysis allows spare capacity on operational diesel/kerosene hydrotreaters to be used to produce biofuels, either by co-processing or produced in batch with fossil fuels.

We also assume that refineries that are stopping their fossil operations can be repurposed to produce advanced biofuels. This greatly reduces the requirement for investment in new stand-alone biofuel or e-fuel plants, and would likely reduce overall investment costs as the repurposed plant could take advantage of existing infrastructure and units, and access existing fuel distribution networks.

By 2050, assuming a standard capacity for a biorefinery of 1 Mtoe per year, the EU+ would require 22 repurposed or new biorefineries in the Max Electron scenario and 48 in the More Molecule scenario to supply the required biofuel demand. This is in addition to co-processing biofuels at any remaining operational conventional refineries.

In addition, in both scenarios, the demand for renewable fuels of non-biological origin (RFNBOs)—hydrogen and e-fuels—grows in the long term as a solution for emissions reduction in hard-to-abate sectors. RFNBO demand in the More Molecule scenario is 11% higher than in the Max Electron scenario by 2050. The overall possible supply of RFNBOs in the EU+ is 111 Mtoe by 2050 in the More Molecule case.

Excluding drop-in e-fuels, the emergence of RFNBOs as a green energy carrier requires development of specific transportation infrastructure for import and use. Multiple hydrogen carriers exist (hydrogen gas, ammonia, methanol, etc.), each with different transportation economics. In the Max Electron scenario, non-e-fuel RFNBO demand is 151 Mtoe, and in the More Molecule scenario it is 160 Mtoe in 2050.

RFNBO demand will come from the hard-to-abate sectors such as industrial, power, refinery use and transport. Overall, the EU+ industrial hydrogen demand for RFNBOs will be based on the target defined by the EU, i.e. 42% by 2030 and, by 2050, an assumed 100% of overall industrial hydrogen demand (excluding the production of hydrogen as a by-product from processes such as reforming and steam cracking, which must be consumed). Demand in the transport sector will come from direct hydrogen use by the ICE and fuel-cell electric vehicle (FCEV) fleet, and from the use of hydrogen to produce e-fuels.

Given the expected maximum possible renewable power capacity by 2050 under the SPGCI Green Rules scenario, and with strong demand for renewable power coming from power, transport and other sectors, the EU+ would have limited renewable power capacity available to meet the expected overall demand for RFNBOs. The EU will therefore need to import more than 50% of its e-fuel requirements in both scenarios.

Table 1 on page 47 shows the evolution of fuel manufacturing plants in Europe. While the number of traditional refineries reduces from 86 to 12 and 14, respectively, in the Max Electron and More Molecule scenarios, the increased demand for liquid fuels in the More Molecule scenario allows 92% of current EU refineries to be retained or repurposed, whereas in the Max Electron scenario 41 refineries would have to be closed without further utilisation.

Table 1: Number of refineries, biorefineries and e-fuel plants in the Max Electron and More Molecule scenarios

a) Max Electron

	Number of conventional refineries running	Number of new biorefineries required	Number of e-fuel plants required	Total
2024	86			86
2030	58	0	1	59
2040	28	0	2	30
2050	12	22	11	45

b) More Molecule

	Number of conventional refineries running	Number of new biorefineries required	Number of e-fuel plants required	Total
2024	86			86
2030	59	0	1	60
2040	29	8	3	40
2050	14	48	17	79

Security of supply

Based on SPGCI analysis, the EU+ maximum potential for additional renewable electricity production from 2024 is estimated at ±3,712 TWh in 2050, of which 51% will be used for hydrogen production in 2050. Domestic generation of RFNBOs (hydrogen and e-fuels) requires additional renewable electricity of more than 1,884 TWh in 2050, which will be a challenge — for context, the total EU+ electricity consumption in 2022 was 2,895 TWh.

In the Max Electron scenario, the total liquid biofuel demand for bio-gasoline, biodiesel, biojet and bioLPG reaches 62 Mtoe by 2050. In the More Molecule scenario, total liquid biofuel demand reaches 94 Mtoe. There is sufficient biomass available in the EU+[3] to meet Annex IX, Part A and Part B biofuels demand, hence there could be sufficient domestic production to meet these requirements without imports by 2050 under both the Max Electron and More Molecule scenarios. Such a demand for biofuels would enhance EU+ fuel security.

In the More Molecule scenario, by 2050, the demand for e-fuels — which includes e-SAF,[6] e-gasoline and e-diesel — is 39.5 Mtoe, and 23.6 Mtoe in the Max Electron scenario. Overall supply capacity for e-fuels in the EU+ grows to 16.0 Mtoe in the More Molecule case and 10 Mtoe in the Max Electron case.

RFNBO production requires large amounts of renewable electricity produced by a combination of wind and solar power; and as mentioned above, the supply of renewable electricity is estimated by SPGCI to be limited. Therefore, the EU+ remains a net importer of RFNBOs and e-fuels in both scenarios. By 2050, RFNBO import volumes vary from 32% of total RFNBO demand in the Max Electron scenario to 39% of total demand in the More Molecule scenario.

In 2030 and 2040, the imbalances between supply and demand of liquid fuels (fossil, bio- and e-fuels) in the EU+ remain relatively similar in both scenarios: a significant excess of gasoline and deficit of diesel in 2030, somewhat reduced in 2040 but countered by a significant deficit in jet/kerosene (approximately a third of the demand will have to be imported).

[6] e-SAF: electro-Sustainable Aviation Fuel — a synthetic jet fuel offering a 90%+ reduction in carbon footprint compared to conventional jet fuel.

The EU+ will have to rely on imports to cover 56% of its e-fuel demand in 2050 in the Max Electron scenario, and 59% in the More Molecule scenario. It is expected that e-fuel imports will come from regions with a high number of sunlight days and low population density, such as the Middle East, North Africa, Chile, Australia and the US Gulf Coast. Imports of e-fuels could include either finished products or e-crude to be refined in EU refineries, depending on the business model of the international e-fuel producers.

In 2050, both scenarios show a similar excess of gasoline, albeit at a much reduced volume. A deficit of jet/kerosene will represent 25% of the demand in the More Molecule scenario, and 33% of the demand in the Max Electron scenario. Diesel will have to rely on the export of approximately 20% of its production, and residual fuel oil and LPG on imports of approximately 50% of the demand in the Max Electron scenario, while the supply and demand of these products are almost equilibrated in the More Molecule scenario, leaving the EU+ almost self-sufficient for these products.

The transition from fossil fuel refining results in a decline in EU+ supply of crude-derived speciality products such as bitumen, petcoke, base oils, and petrochemical feedstocks such as naphtha, propylene and aromatics. Bitumen and petcoke cannot be cost-effectively produced from renewable feedstocks, and the EU+ will have to rely on imports for the majority of the supply in 2050. Approximately 50% of base oil demand will have to be imported in the Max Electron scenario (1.7 Mtoe), while these imports are reduced to approximately 35% of the demand in the More Molecule scenario (1.2 Mtoe).

The reduction in propylene and aromatics production from conventional refineries could be replaced by additional production from the petrochemical industry, which would require additional naphtha supply for steam crackers. This additional 12 Mtoe naphtha demand could be met in 2050 in the More Molecule scenario, while it would have to rely on imports in the Max Electron scenario.

Conclusions

The Max Electron scenario requires an unprecedented expansion of renewable electricity infrastructure, while the More Molecule scenario relies on an important development of sustainable feedstock availability. Both scenarios demand sustained policy clarity, supportive carbon pricing, and cross-sectoral cooperation. A hybrid path combining electrons and molecules appears most robust for security of supply and industrial competitiveness and resilience.

The Concawe-SPGCI study shows that both pathways can deliver net-zero emissions by 2050. The transition will reshape Europe's refining industry into a low-carbon ecosystem anchored by innovation, hydrogen and carbon management.

Report-specific disclaimer

Neither scenario is intended as a forecast or a validation of the probability or feasibility of realising the various assumptions in the study, such as the rate of electrification or availability of renewable energy and green hydrogen for the transport sector, nor do they assess the impact on competitiveness of the

European economy or the affordability for consumers or industries. These scenarios are two theoretical cases for meeting the EU's 2050 net-zero objective.

The choice of these two theoretical scenarios should not be considered as exhaustive for meeting the 2050 net-zero emission objective, as this study does not include other scenarios that could potentially achieve the objective by modifying other key decarbonisation opportunities such as, for example, greater uptake of carbon capture and storage (CCS), additional bioenergy carbon capture and storage (BECCS), blue hydrogen or other technological advancements in sectors other than transport.

Furthermore, the economic modelling behind the scenarios did not take into account refinery-specific parameters such as petrochemical integration, individual refinery energy efficiency, etc. The conclusions regarding the necessary reduction of refining capacity should therefore not be interpreted as an indication of the level of any individual European refinery.

Acknowledgement

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Further reading

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