A Clean Planet for all: an impact assessment of the potential implications for the refining system and the link with 'Refinery 2050'

Focusing on three of the scenarios defined in the European Commission's long-term strategy, *A Clean Planet for all*, Concawe has published a report that assesses the potential reductions in CO_2 emissions, together with the implications for the EU refining sector in terms of the required investments, and the barriers, enablers and associated risks. This article provides a brief summary of the Concawe report.

Objective

The European Commission's long-term strategy, *A Clean Planet for all*[1,2] published by DG CLIMA in 2018, analyses different long-term scenarios that could lead to significant reductions in greenhouse gas (GHG) emissions on the way towards a carbon-neutral and circular European economy by 2050.

Concawe has published a report that analyses three of the scenarios presented in the DG CLIMA publication. It examines the implications for the EU refining sector, assesses the CO_2 emission reductions that could be achieved through the whole value chain, and provides an estimate of the investments required to develop new plants and adapt existing refinery infrastructure, while also exploring key barriers and enablers associated with realising these scenarios.


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A Clean Planet for all

A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy

Concawe's new report focuses on three scenarios defined in the European Commission's long-term strategy, *A Clean Planet for all*, published in November 2018.

The Concawe report focuses on the following three EU scenarios (each compared to 1990):

- **Baseline**, with current policies to 2030[1] which achieve GHG emission reductions of 45% by 2030 and 60% by 2050;
- **P2X (power-to-fuels/e-fuels)**, achieving an 80% reduction in GHG emissions across the whole EU economy; and
- **1.5TECH (climate neutral scenario)**, achieving a 100% net reduction in GHG emissions (including sinks).

Concawe's report also aims to answer the following key questions:

- What are the implications for the European refining system in 2050?
- What are the results in terms of GHG emission reductions that could be achieved across the whole value chain?
- What are the external requirements, as well as the key barriers and enablers, for the realisation of such scenarios?
- How will the domestic production/import/export balance be impacted?

[1] 45% reduction in GHG emissions by 2030, and 60% reduction by 2050.

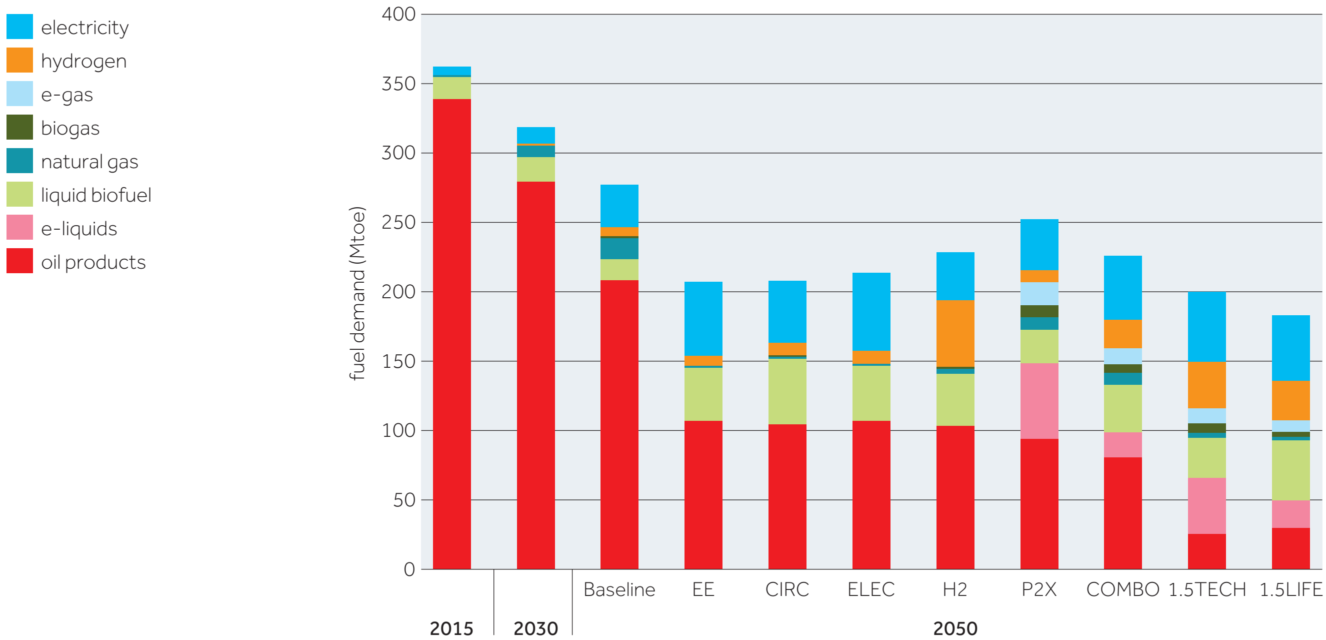
Product demand

Transport fuels

All scenarios rely on a combination of energy sources and carriers to satisfy the demand for transport, and on the substitution of fossil fuels increasing with the GHG reduction ambition (see Figure 1).

- Domestic demand for oil-based products decreases steeply towards 2050 — by up to 90% in the 1.5TECH scenario compared to the current level. Aviation fuel becomes dominant in the total transport fuel demand, and retains the largest proportion of fossil material.
- Although the contribution of total liquid fuels (oil products, e-liquids, liquid biofuel) to transport is reduced, they retain a significant share with 50% of the 2050 domestic demand in the most ambitious (1.5TECH) scenario.
- The baseline case still shows a large fossil contribution in all liquid product pools. The fossil contribution is significantly reduced in the P2X scenario (45%) and even further in the 1.5TECH scenario (10%).
- Electrification becomes a main feature for transport through both the direct use of electric road vehicles and the use of so-called e-fuels derived from captured CO_2 and hydrogen produced mostly from renewable electricity. The P2X scenario is particularly ambitious for e-fuels in road transport (up to 60%).
- Biomass also plays an increasingly significant role.

Figure 1: Fuel demand in the transport sector according to *A Clean Planet for all* [1]



Other products

The demand for petrochemicals (olefins, aromatics), LPG, bitumen, lubes and waxes are not specifically mentioned in *A Clean Planet for all*. The Concawe study builds on figures previously considered in Concawe's 'Refinery 2050' study.[3]

Modelling

The three scenarios were simulated on a pan-EU refinery system basis using Concawe's RafXL[2] model, with the objective of matching demand in terms of both tonnage and origin distribution (fossil/bio/e-fuels) for each main product pool. The feedstocks and processing schemes considered were:

- crude oil and conventional refinery processes;
- lipids (vegetable oils) hydrotreated to middle distillates;
- woody biomass to liquids via gasification and Fischer-Tropsch (FT) synthesis; and
- own (captured) and imported CO_2 plus electrolytic hydrogen to e-fuels.

A 'high jet' mode (validated with confidential proprietary data from different technology providers) was introduced for the FT product processing to support the high demand for jet fuels. As an assumption, it was considered that components from different origins would mostly be produced in separate plants (or even sites) so that they could be routed independently to the appropriate product pool. Given the existing infrastructure and facilities already available at refineries, some of which would be underutilised, and the potential synergies with the new conversion technologies, it is reasonable to assume that existing refining sites will attract a good number of these new plants which could be integrated into the existing systems (for additional details see Concawe report no. 9/19, *Refinery 2050: Conceptual Assessment*.[3])

Results

Demand

With the level of flexibility afforded by the segregation of fossil, bio and e-streams, and the availability of a 'max jet' hydrocracking mode, the RafXL model demonstrates that it would be possible to meet the 2050 demand for the main products in all three of the selected scenarios described in *A Clean Planet for all*, both in terms of tonnage and origin (feedstock) distribution, as well as meeting the demand for the other products, but only with some non-negligible burdens described below.

[2] As described in Concawe report no. 9/19,[3] Concawe's RafXl simulation tool was used with the objective to best match both the EU domestic demand and origin distribution for all three transport fuel pools, while also meeting the demand for other products and minimising surpluses (exports out of Europe). The modelling exercise was done for the whole of the EU refining industry notionally operating as a single refinery, with the total European refinery plant capacities.

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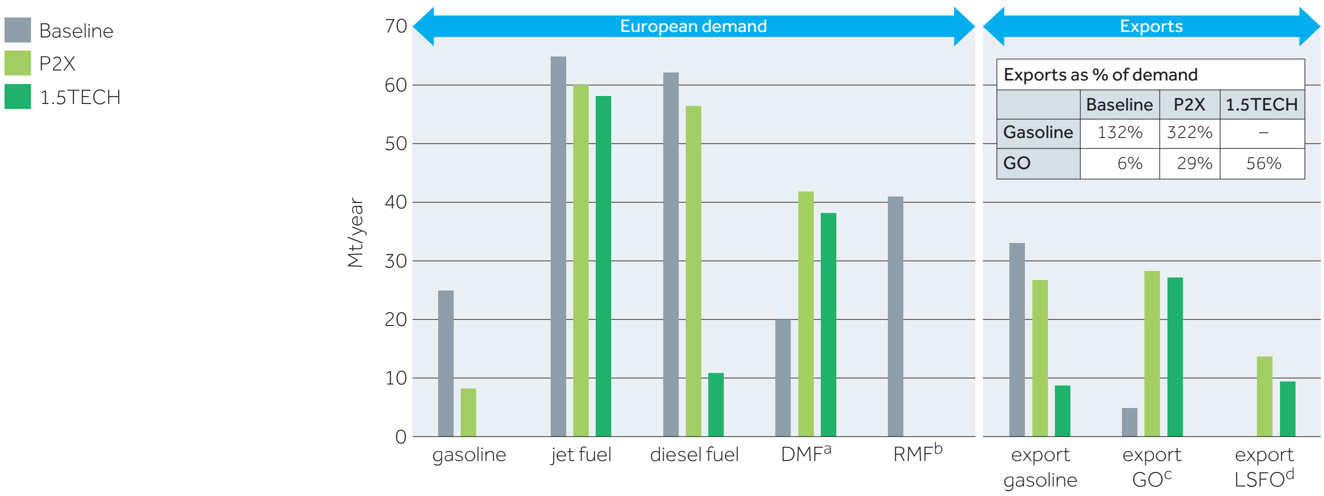
Figure 2: European demand and exports



Exports as % of demand	Baseline	P2X	1.5TECH
Gasoline	132%	322%	–
GO	6%	29%	56%

[a] diesel marine fuel
[b] residual marine fuel
[c] GO refers to exported gas oil, all the middle distillates left over
[d] low-sulphur fuel oil (RMF or other grades)

The main implications of the three selected scenarios are as follows:

- The large quantities of middle distillates required, and particularly jet fuel with a significant fossil component, coupled with weak gasoline and diesel demand and the disappearance of marine fuel oil in the most advanced scenarios, results in significant surpluses of gasoline, gas oils and heavy fuel oil (exports out of Europe, overwhelmingly comprised of fossil components).
- Surpluses can be reduced, but not totally eliminated, by relaxing the origin distribution constraints defined in the European Commission's report.
- Technologies that address the gasoline/distillate balance (such as oligomerization) or modifications of existing hydrocrackers would only have a limited impact.

The main challenges

The fossil fuels consumption mix anticipated in the European Commission's report is so weighted towards jet fuel that, as an outcome of Concawe's analysis, it was identified that it would not be feasible to achieve these yields in the average EU refinery without the consequent surplus of different types of fuels (mainly fossil with a percentage of renewables), which would need to be exported out of the EU. The percentage of fuels of renewable origin exported would potentially be transported to countries that could not valorise their renewable nature, adding an additional cost of production versus fossil. This is envisaged to be highly uneconomical for the EU system.

In addition to the export issue, and although the surplus volumes of gasoline, gas oil and heavy fuel oil (mostly fossil based) are of a similar order of magnitude to historical EU trading figures, it is questionable whether the estimated levels of 'fossil' exports required to meet the analysed scenarios could be considered sustainable in a low-carbon 2050 world. Eventually, this could mean that the EU would be reducing emissions domestically at the cost of increasing them somewhere else.

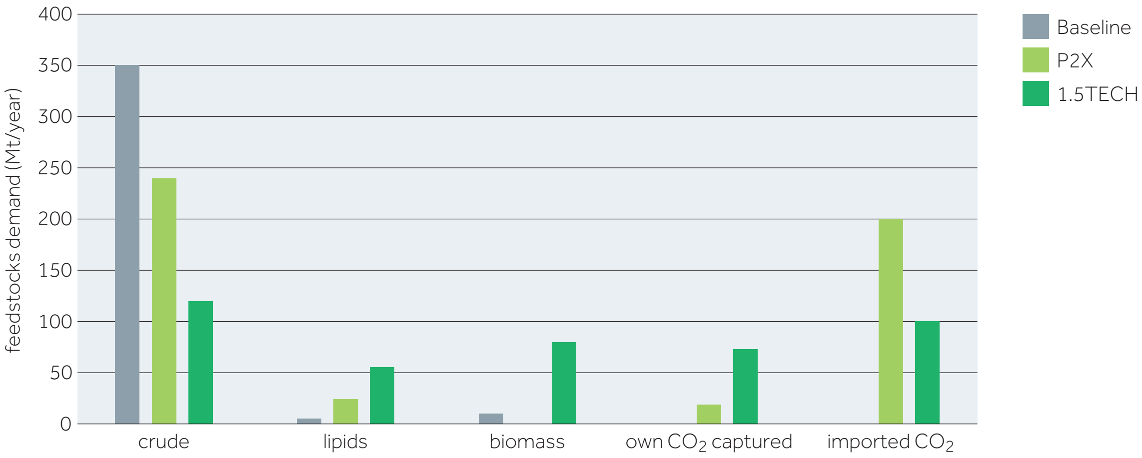
Implications for the refining industry

Feedstock requirements

In all cases, the crude oil volume required to meet the total demand for transport fuels (with the share of fossil components as defined in *A Clean Planet for all*) was higher than the minimum of about 65 Mt/year set by the demand for bitumen.

The estimated demand for lipids and biomass were within the maximum availability forecast for 2050.[4]

Figure 3: Demand for feedstocks



The main challenges

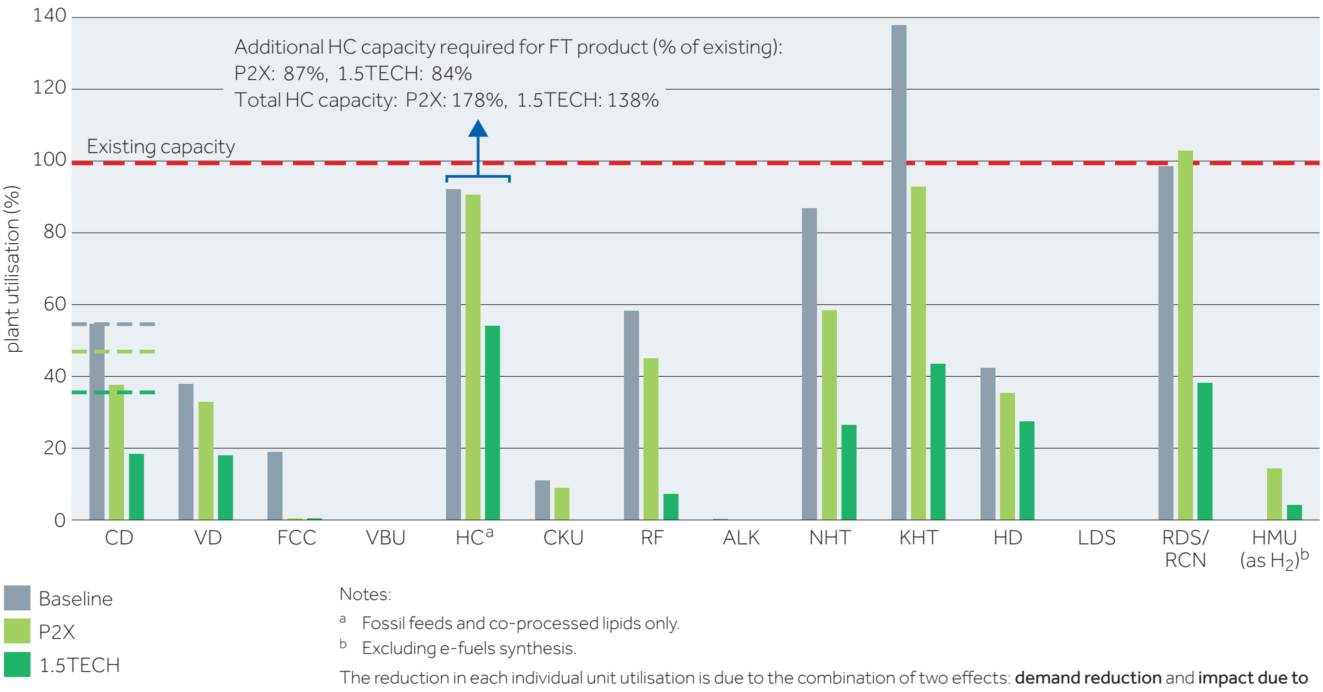
The emphasis on e-fuels (domestically produced in Europe in this assessment) sets a very high target for CO_2 'imports', as production within the EU refining system only meets a fraction of the total CO_2 requirement (9% in the P2X scenario and 42% in the 1.5TECH scenario). This requirement of CO_2 as a feedstock for the refinery system could foster the creation of industrial hubs (where the CO_2 comes from other industrial sites) or the development of technologies such as direct air capture.

Key issues such as the mobilisation of high volumes of sustainable feedstocks at the European level are also major caveats with regard to the 2050 demand scenarios.

Refinery plant utilization and new capacities

Conventional refinery plants are heavily underutilised, with the exception of hydrocrackers, kerosene hydrotreaters and residue converters. Processing the raw synthesis material will require up to a twofold increase in existing EU hydrocracking capacity, or the repurposing of some existing hydrotreaters.

Figure 4: Refinery plant utilisation



CD: Crude distillation

VD: Vacuum distillation

FCC: Fluid catalytic cracking

VB: Visbreaking

HC: Hydrocracking

CKU: Coking

RF: Catalytic reforming

ALK: Alkylation

NHT: Naphtha hydrotreating

KHT: Kerosene hydrotreating

HD: Gasoil hydrodesulphurisation

LDS: Atmospheric residue desulphurisation

RDS/RCN: Vacuum residue desulphurisation/conversion

HMU: Hydrogen manufacturing (SMR)

Notes:

[a] Fossil feeds and co-processed lipids only.

[b] Excluding e-fuels synthesis.

The reduction in each individual unit utilisation is due to the combination of two effects: **demand reduction** and **impact due to the alternative feedstocks** fed into the refinery, replacing crude oil (in some cases, the alternative feedstocks will be fed directly into HC or FCC units, minimizing CD/VD utilisation). As a visualisation of the impact of these combined effects, the dotted lines on the figure indicate the current capacity and general level of demand reduction in each scenario, applied to the crude processing capacity.

New plants would be required to process lipids into marketable diesel, and biomass and CO_2 into liquid fuels. Based on today's commercial practice, up to some 40 plants/trains would be required to process lipids. Although biomass-to-liquids (BTL) technology has not yet reached commercial scale, single train capacities of 200 kt/year of liquid product are considered feasible, which would suggest a requirement for up to 50 plants/trains across Europe. E-fuels plants are very much unchartered territory in terms of hydrogen production at scale and CO_2 conversion. The FT stage would be very similar to proposed BTL plants, and small sizes could potentially be envisaged in Europe (~0.2 Mt/year of liquid product). However, there is considerable uncertainty with regard to the future capacity of these plants, and larger ones — such as gas-to-liquids (GTL) plants — could also be deployed in certain favourable areas with capacities of up to 1 Mt/year of liquid product. As a reference, they will require about 3 Mt/year CO_2 and 3 GW of electricity generation capacity for 1 Mt/year of liquid product.

The main challenges

Major challenges would lie ahead for the scaling up of biomass-to-liquids plants, and the development of large e-fuels plants in terms of CO_2 availability and distribution/transport systems, electricity generation capacity and supporting infrastructure, and very large electrolyser banks.

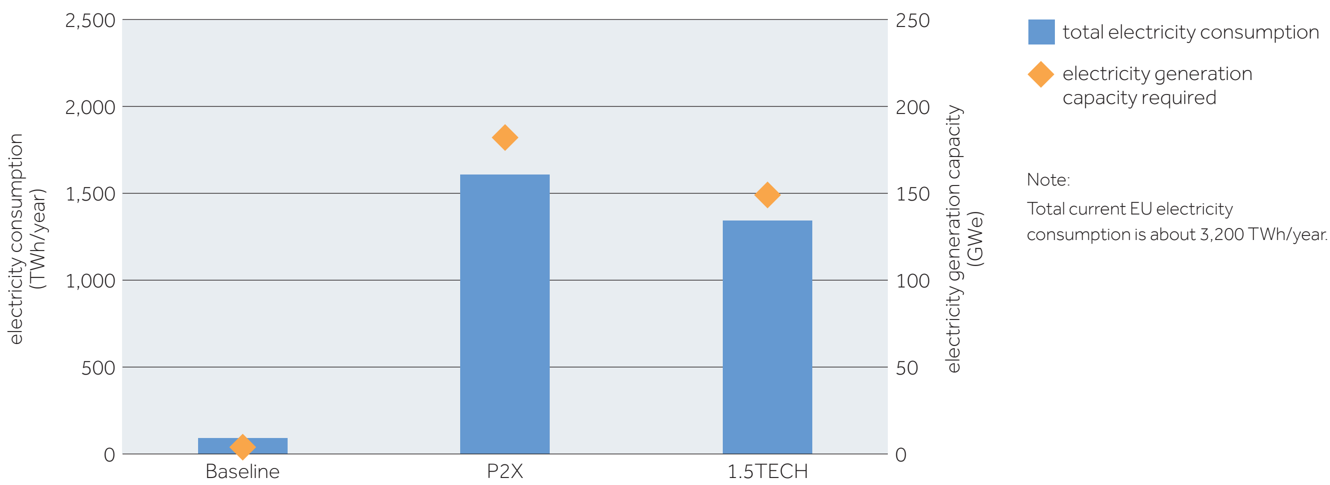
Energy consumption

Energy consumption is dominated by electricity required to produce hydrogen for the refinery and, overwhelmingly, for e-fuels manufacture. Electricity consumption for conventional refining, as in the Baseline case, is dwarfed by the demand for electricity required for e-fuels production in the other scenarios.

With low crude intake and the use of CO_2 capture, fossil site emissions are very low in the P2X scenario (about 5% of current emissions) and virtually eliminated in the 1.5TECH scenario. At the same time, potential emissions from fuel products are reduced as a result of the decreasing proportion of fossil material in their make-up.

As imported grid electricity is not assumed to be fully renewable, there is still a fossil component in the imported utilities.

Figure 5: Electricity consumption



Note:
Total current EU electricity consumption is about 3,200 TWh/year.

The main challenge

In the P2X scenario, electricity consumption would account for about half of today's total demand for electricity in the EU.

CO_2 emissions

Table 1 shows the breakdown of CO_2 emissions according to the refinery modelling conducted.

Table 1: CO_2 emissions breakdown (Mt/year)

	Baseline	PSX	1.5TECH
Total net from site Total (fossil + non-fossil) CO_2 emitted on site; can be negative where CO_2 is absorbed by e-fuels	60	-192	-69
Total from fuel products Total (fossil + non-fossil) potential CO_2 from all carbon in fuel products combustion (including exports)	842	784	506
Fossil from site Fossil CO_2 emitted on site: the fossil content of the actual emissions	46	5	1
Fossil from fuel products Potential CO_2 from fossil carbon in fuel products combustion (including exports)	825	552	222
Fossil from utility imports Fossil CO_2 emitted when generating imported electricity and gas	6	30	7
Percent reduction in direct CO_2 emissions vs 1990	62%	96%	99%

With low crude intake and the use of CO_2 capture, fossil site emissions are very low in the P2X scenario and virtually eliminated in the 1.5TECH scenario. At the same time, potential emissions from fuel products are reduced as a result of the decreasing proportion of fossil material in their make-up.

The direct (fossil from site) CO_2 emissions reduction (compared to 1990) in the EU refining system ranges from 62% in the Baseline to 96% (P2X) and 99% (1.5TECH). The P2X case achieves a greater reduction in CO_2 emissions from EU refineries (96%) than the claimed reduction across the whole EU economy (80%). The 1.5TECH case almost achieves net zero emissions in EU refineries, while a 100% reduction is claimed for the whole EU economy.

Investment estimate

Investment in production sites, which are dominated by e-fuels production, could range between G€250 and 400 for the whole EU refining system in the P2X and 1.5TECH scenarios.

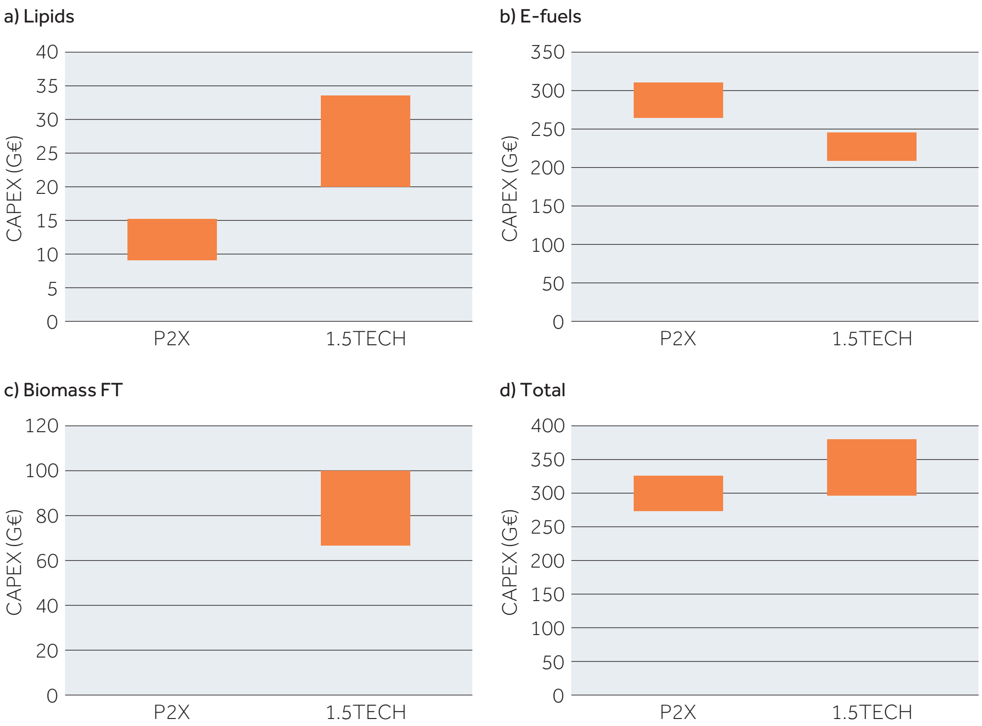
Introducing alternative feedstocks in the refinery environment at the scale discussed above would require investment in brand new plants for the front-end processing of these feedstocks, extensive modifications and revamping of existing plants for further processing and treating of the raw products, and extensive adaptation of ancillary facilities such as import terminals, tankage, etc.

An estimate of the CAPEX associated with the new processes has been undertaken, noting that the main investments required to implement the scenarios are related to the processing of lipids and biomass and, most importantly, to the massive production of e-fuels that is envisaged.

The CAPEX on electricity generation has not been included, nor has the CAPEX on the supply chain or additional investment derived from the repurposing/adaptation of existing refineries to accommodate the new technologies.

Based on the best estimate of the specific CAPEX ranges for such plants as discussed in Concawe's 'Refinery 2050' report,[3] Figure 6 shows the total investments that could be required.

Figure 6: Ranges of CAPEX associated with the development of new processes

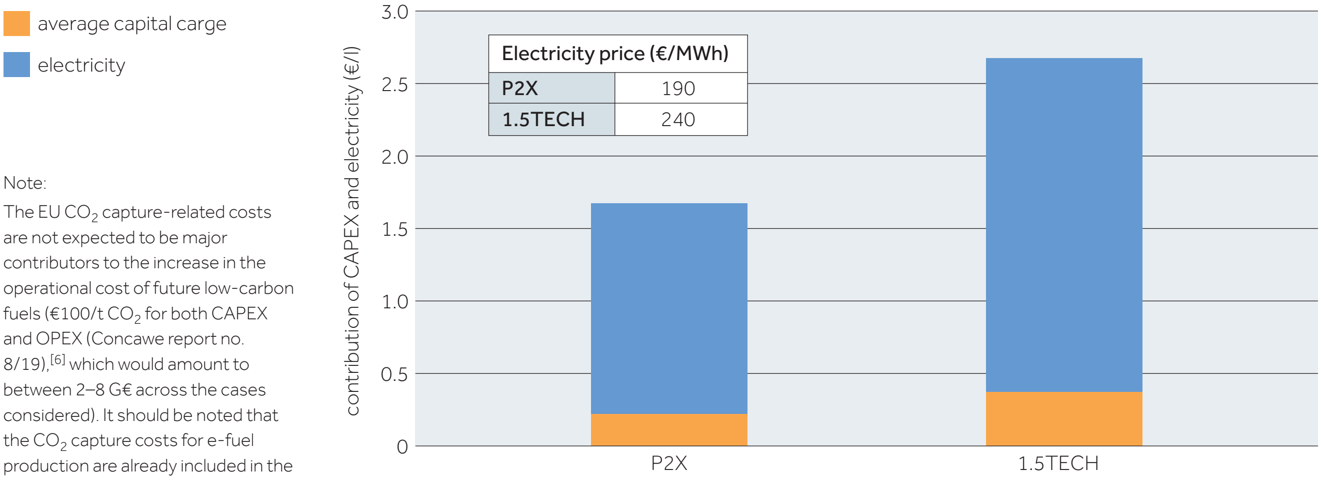


Basis	Capacity per unit (Mtoe/year)	CAPEX per plant (M€)	M€/kt/year product[a,b]
New HVO plants	0.5	275	0.55
Lignocellulosic	0.15	610–900	4.0–6.0
E-fuels	0.2	400–650	2.0–3.3[c]

[a] Capacities are expressed in terms of liquid product; toe/t factor=1 for liquid products.
[b] CAPEX data aligned with Concawe report no. 9/19.[3]
[c] Other new sources[5] are reporting lower CAPEX figures (below 3 M€/kt/year) than in Concawe report no. 9/19 (3.77–4.43 M€/kt/year).

CAPEX accounts for only a fraction of the costs involved. The main variable cost would be that of electricity. Figure 7 shows the contributions to the fuel unit cost in €/l, taking into account the annualised CAPEX (the average of the above figures plus a 15% capital charge) and electricity price in line with the EU Commission's forecast. The cost of the small amount of natural gas and other operating costs such as personnel, maintenance, etc. are not represented here, but they would be dwarfed by the very high cost of electricity.

Figure 7: Contribution of CAPEX (average capital charge) and electricity to fuel unit cost



Note:
The EU CO_2 capture-related costs are not expected to be major contributors to the increase in the operational cost of future low-carbon fuels (€100/t CO_2 for both CAPEX and OPEX (Concawe report no. 8/19),[6] which would amount to between 2–8 G€ across the cases considered). It should be noted that the CO_2 capture costs for e-fuel production are already included in the e-fuel related figures.

It is important to note that the Concawe study is a conceptual assessment and further implications in terms of the level of investment required across the whole refining system have not been assessed in detail.

Conclusions

This Concawe study highlights the risks associated with the selected scenarios defined in the EU Commission's report, *A Clean Planet for all*, which will add significant burdens to the EU refining system in 2050. Based on the information presented in this article, it can be seen that the materialisation of these scenarios could potentially lead the refining system to a point where meeting the defined demand (and fuel composition), as described in the EU Commission's report, would not be economically feasible for the refining system in Europe, and could lead to refinery closures, with supply being met mainly by imports of fossil jet fuel into Europe from other regions of the world, with no benefit for climate change globally.

Although the combination of the alternative feedstock pathways has been modelled to occur simultaneously in the same refinery, different combinations of routes may be followed by individual refineries (depending on factors such as the proximity to a specific resource, geographic location, initial refining configuration, etc). All of this is subject to individual strategic plans and is out of the scope of this Concawe study.

This study cannot therefore be considered as a roadmap for the whole European refining system but as an initial exploration of the potential consequences at macro-level to provide the basis for engagement in a more detailed technical debate on the subject with the European Commission.

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