Refining 2030

The major uncertainty characterizing the global energy landscape impacts particularly on transport, which remains the virtually-exclusive bastion of the oil industry. The industry must therefore respond to increasing demand for mobility against a background marked by the emergence of alternatives to oil-based fuels and the need to reduce emissions of pollutants and greenhouse gases (GHG). It is in this context that the "Refining 2030" study conducted by IFP Energies nouvelles (IFPEN) forecasts what the global supply and demand balance for oil products could be, and highlights the type and geographical location of the refinery investment required. Our study shows that the bulk of the refining investment will be concentrated in the emerging countries (mainly those in Asia), whilst the areas historically strong in refining (Europe and North America) face reductions in capacity. In this context, the drastic reduction in the sulphur specification of bunker oil emerges as a structural issue for European refining, in the same way as increasingly-restrictive regulation of refinery CO_2 emissions (quotas/taxation) and the persistent imbalance between gasoline and diesel fuels.

Modeling principles

The refining model used in preparing this projection is a linear programming model in which the world is broken down into nine regions, each characterized in terms of:

- crude oil production scenarios (compatible with the forecast trend in reserves) and demand for oil products (net of oil substitutes, such as XtLs (X to Liquids from coal or natural gas) and biofuels);
- a single aggregated refinery (representing all existing capacity in the region) and a comprehensive set of costs (raw materials, processes and transport of crude oil and product).

The supply/demand balance is the result of minimising the operating cost of the global refining industry. This purely economic optimisation does not therefore reflect either national or regional industrial strategies. Neither does it take into account any technology-based contribution (CO_2 capture and storage, "electric furnaces", etc.) to reducing refinery energy consumption and greenhouse gases emissions. The optimum solution arrived at takes the following into account for each region: the cocktails of crudes processed, pools composition and quality, the net balance of crude and product trading between regions, the investment required and the cost of sourcing finished products.

In conclusion, this model provides an overview of refining fundamentals, and makes no claim to address all the complexities involved.

Hypotheses underlying the scenarios studied

This study assumes a background context of sustained global economic growth (averaging 4% per annum) and moderate energy transition, with crude priced at $100 per barrel throughout the period. Two overall scenarios have been considered: a trend-based scenario (the reference or "business as usual" scenario), which is compared with the second "green" scenario based on increasing rates of biofuel usage, transport energy efficiency, regulation governing pollutant (SO_2) and CO_2 emissions from the refining industry and the upgrading of heavy crudes.

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The contribution from (1st and 2nd generation) biofuels in 2030 is set at 5.2 million barrels per day (Mbbld) of oil equivalent in the green scenario, compared with 3.8 Mbbld of oil equivalent in the reference scenario: in both cases, the strong growth of these products is consistent with current European and North American commitments. At the same time, the automobile CO_2 emissions targets set for 2020 at 95 g of CO_2 per km for Europe and 35 miles per gallon (mpg) for North America have been tightened to averages of 80 g/km and 53 mpg on the basis of foreseeable developments in internal combustion engines and a more substantial move towards electric and/or hybrid vehicles in the overall fleet. More modest progress is also forecast for light and heavy duty vehicles (in the absence of more structural changes in the road transport sector: modal shift, etc.). Improvements in aircraft occupancy rates and engine efficiency are also taken into account to varying degrees, depending on the scenario concerned. The final differences between the green scenario and the reference scenario are the application of a CO_2 penalty of $100 per tonne of emissions by both refining industry and extra-heavy oils upgrading sectors (applied from the first tonne onwards) exclusively for the mature refining industry regions of Europe and North America. No indirect effect of this penalty on the demand for oil has been considered in this study.

In both scenarios, all regions also apply the drastic reduction in bunker oil sulphur content recommended by the International Maritime Organization (IMO), and the reduction to 600 mg/Nm^3 of refinery SO_2 emissions.

Finally, compared with 2005, global demand increases by 8% in the green scenario to 93.7 Mbbld (including self-consumption); a figure significantly lower than the 23% increase seen in the reference scenario (104.3 Mbbld). Both scenarios share the marked contrast between mature refining regions and the rest of the world. The emerging countries therefore see strong growth in demand, especially from Asia (including China), with 64% in the reference scenario and 40% in the green scenario. Conversely, the North American and European regions show a significantly lower demand in 2030 than in 2005, the effect of which is more marked in the green scenario (–27 and –25% respectively) than in the reference scenario (–18 and –12%) Table 1. This results in a relative reduction in their contribution to meeting global demand, from 50% in 2005 to 35% in 2030, and an increase in Asia from 29% to 39% over the same period.

In more detailed terms, the proportion of heavy products declines in all regions, with a switch away from "terrestrial" heavy fuel oils to bunker oils. In 2030, these will therefore account for more than two-thirds of all fuel oils produced and consumed (excluding refineries), as a result of the growth in shipping traffic and the erosion of industrial fuel oils. The proportion accounted for by distillates in reference global demand rises slightly, with the ratio of diesel to total automobile fuels moving from 43% to 49% between 2005 and 2030. This result is driven essentially by the mature regions: if North American demand remains focused on gasoline, its proportion of distillates increases (ratio rising from 27% to 40%), whilst the trend in Europe keeps growing (ratio rising from 61% to 76%). But this trend in the historic countries is largely offset at global level by the significant rise in sales of private automobiles — the majority gasoline-powered (plus hybrids) — in emerging countries (principally India and China, all being characterized by a ratio which trends from 51% to 43% over the period).

Table 1

Demand for finished products in the reference and green scenarios after deduction of oil substitutes – 2030

Mt/yr	North America		Europe		World	
	Ref.	Green	Ref.	Green	Ref.	Green
LPG	59	59	29	29	255	250
Naphtha	20	20	49	49	346	331
Gasoline	304	240	71	54	1 045	872
Jet + kero	106	73	74	51	509	364
Heating oil	76	76	49	49	459	445
Diesel	201	197	231	180	1 006	864
Fuel oils	16	16	19	19	164	161
Bunker oil	33	32	65	62	280	263
Other	47	47	47	47	292	283
Total	861	760	635	540	4 356	3 833
2005-30	–18%	–27%	–12%	–25%	23%	8%

Source: IFPEN

In terms of projections for crude oil availability in 2030, Table 2 shows that the supply of fossil fuel resources in the reference scenario is 96.9 Mbbld, of which 78.8 Mbbld are conventional crudes, and 6.5 Mbbld are upgraded extra-heavy crudes[1] (a combined increase of 10.2 Mbbld relative to 2005), plus 9.8 Mbbld of condensates (gas production by-products) and 1.8 Mbbld of synthetic fuels produced from coal (two-thirds) and gas.

As a result of reduced demand, fossil fuel supply still dominates the green scenario, but at the reduced rate of 85.4 Mbbld, of which 76.2 Mbbld are conventional crudes and upgraded extra-heavy crudes, 7.7 Mbbld are condensates and 1.5 Mbbld are synthetic fuels.

(1) Extra-heavy crudes are most frequently upgraded, i.e. pre-refined in an on-field plant prior to processing in a traditional refinery

Table 2

Supply of crudes and oil substitutes according to the IEA[2] and IFPEN – 2030

Mbbld	2055	Green 2030	450 ppm 2030	Ref. 2030	Base 2030
	Obs.	IFPEN	IEA WEO 2009	IFPEN	IEA WEO 2009
Crudes[(a)]	75.1	76.2		85.3	84.1
CtL & GtL	0.2	1.5		1.8	
Condensates	6.7	7.7		9.8[(b)]	18.9[(b)]
Total fossil fuel supply	82.0	85.4	87.0	96.9	103.0
Refining capacity	81.8	83.9		95.1	
Biofuels[(c)]	0.53	5.2	5.8	3.8	2.7
Processing gain	3.2	3.2	(1.9)	3.6	2.2
Overall demand[(d)]	94.6	93.7	(94.7)	104.3	107.9

Source: IFPEN, IEA

(a) Conventional crudes and extra-heavy crudes after upgrading (+CtL & GtL for base 2030 in the IEA WEO 2009).
(b) Boundary difference between crudes and condensates
(c) Product equivalence
(d) Including self-consumption by the refining industry

Key outcomes of the study

A persistent mismatch between refining and the structure of demand in the mature regions

On the basis of minimising the marginal production costs of products (without reflecting national or regional industrial strategies), the model "considers" it economically viable for both North America and Europe to reduce their refining activity levels and to maintain their dependence on external capacity[3]. North American refining capacity therefore adapts to the change in demand (a sharp decline and rebalancing in favour of diesel) by means of a significant reduction in refinery production (–205 Mt, equivalent to –19%), a fall in its gasoline production and an increase in diesel production in proportion to demand. Illustrated by a significant reduction in the gasoline/diesel marginal cost ratio (from 1.7 to 1.1 over the period), this North American adaptation is made possible by the existence of a structural surplus of gasoline in Europe (low marginal cost and acceptable cost of transport to North America), maintaining exports to North America at a level comparable to that seen in 2005, i.e. 21 Mt (Figure 1).

In Europe's strained diesel market, this gasoline surplus is maintained due to a lack of profitability from diesel-orientated investment. This trend is also encouraged by the ongoing Russian diesel surplus (low transport cost), whose export to Europe grows strongly to 46 Mt in 2030 (compared with 28 Mt in 2005). So in 2030, Europe has a "reasonable" level of consolidated refining capacity as a combined result of the Russian diesel surplus (which it imports) and the North American gasoline shortfall (which it is helping to reduce).

Applying a CO_2 penalty solely to the emissions of refineries in the mature refining regions accentuates these trends overall, even where demand remains unchanged. Since Europe has a Russian diesel resource "exempt" from this sanction, it has an incentive to import that fuel until the point where the cost of supply becomes equivalent to its tax-inclusive production cost: these imports increase by 14 Mt compared with the reference scenario to 60 Mt. European refining then focuses on increased production of gasoline from a suitable cocktail of crudes, and increases its exports to North America by 12 Mt to 33 Mt.

In the green scenario, the CO_2 penalty, combined with the steeper fall in European demand, reduces the surplus of gasoline in Europe and, as a result, its flow to North America, and justifies the continuation of European imports of Russian diesel at 58 Mt.

We would emphasize that these outcomes must be qualified by the fact of competition from other regions keen to export gasolines to the USA. Analysis of the marginal costs involved in supplying the North American market with gasoline shows that the Middle East and Africa, and even South America, are competitive, despite higher transport costs. It is clear that increased competition to supply this product would lead to significant pressure on export prices, and even reduced market potential for Europe in North America, thereby weakening a European model based on a structural imbalance between its demand (max. diesel) and the productivity of its refineries. Another possible development that would naturally aggravate the European refining situation would be if North America also moved to a position of surplus as a result of a more significant fall in demand or an increase in its condensate resources (from shale gas).

Migration of investment in refining

Required investment in the refining industry for the period 2005-2030 is calculated at around \$391 billion in the reference scenario and \$287 billion in the green scenario (Table 3). These figures, which exclude expenditure on maintenance and the replacement/revamping of outdated units[4], correspond to an annual average of \$16 billion and \$11 billion respectively; figures significantly lower than

(2) The IEA WEO 2011 gives a slightly different picture of global demand in 2035; 103.7 Mbbld for the New Policies scenario and 86.1 Mbbld for the revised 450 ppm scenario, which illustrates a more rapid decline in demand for oil than that suggested in the WEO 2009
(3) This effect was observed during the 2008 global crisis

(4) Identification of these outdated units requires highly data and does not form part of this study

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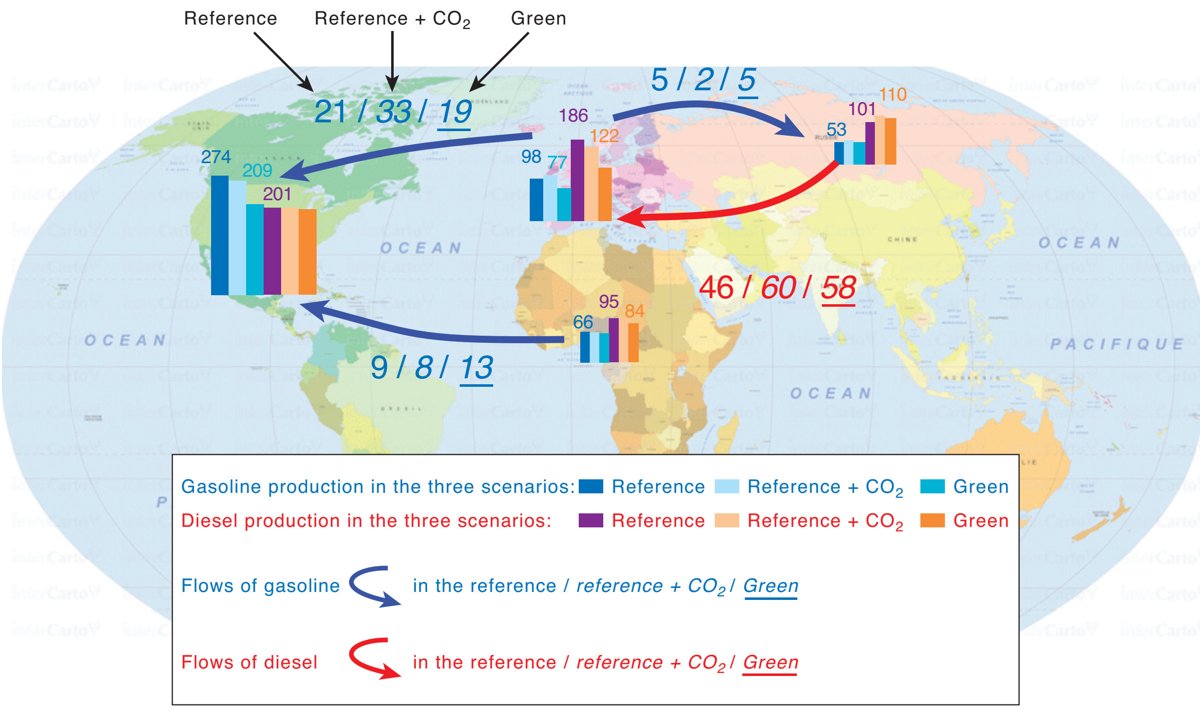
Fig. 1 – Main trade flows from/to Europe – 2030



Source: IFPEN

the $23 billion per year seen over the last decade. Although refining continues to provide the majority of global fuel supplies, in the reference scenario, the investment required for refining alone accounts for only 39% of the total investment required to meet demand, since a considerable proportion is now focused on the upgrading of extra-heavy crudes ($174 billion over the full period), on first- and second-generation biofuels ($265 billion) and on coal liquefaction and natural gas conversion ($152 billion). In the green scenario, production of biofuels attracts as much as 50% of total required investment, whilst accentuating the decline in conventional refining (26%).

Investment in refining is concentrated principally in Asia in both scenarios, accounting respectively for 56% and 45% of the global total, and only for 12% and 8% for Europe and North America combined. In the reference scenario, investment in mature regions is confined to the absolute minimum required to track market trends: diesel desulphurisation in Europe and the USA, traditional conversion (hydrocracking) and deep conversion in Europe (desulphurisation of residues and cokers) in response to the sulphur specifications of bunker fuel oils. On the other hand, the emerging countries see the construction of new refineries, and although traditional conversion and desulphurisation of diesels receive comparable levels of investment, the emphasis at global level is on deep conversion.

Table 3

Expenditure and investment structure in the reference scenario without a CO_2 penalty – 2030

	World	North America	Europe	Asia
Total expenditure in US$ billion(a)	994			
Upgrading	174	108	0	0
XtL	152	7	0	106
Biofuels(b)	265	114	50	56
Hydrogen	12	1	2	7
Refining	391	25	21	217
Detail for refining in Mt/yr				
Topping	587			440
HDS of diesel	778	214	98	240
Simple conversion(c)	511	12	16	314
Deep conversion(d)	284		15	140

Source: IFPEN

(a) Excluding renewals, maintenance, etc.
(b) Excluding capacity already built in 2010. 56% G1 and 44% G2
(c) FCC, hydrocracking and VGO pre-treatment
(d) Coking, residues HDS and RCC

As a result of the global decline in demand, the level of investment in the green scenario is below that of the reference scenario, with particular emphasis on reduced investment in desulphurisation in Europe and North America. However, despite more moderate growth, the IMO specifications require Europe to continue investing in the hydroconversion of residues, whilst the USA focuses more on imports to meet this demand. In the hypothesis where compliance with the IMO regulation cannot be ensured by onboard desulphurisation of ship fumes or the development of alternative "fuels" (LNG, etc.), the issue of bunker fuel oils becomes a structural consideration in the Europe region.

It should be noted that the package of regulations and restrictions applied in the Europe region (dieselisation + IMO specifications) results, in a first set of simulations, in a doubling of demand for West African and even North African crudes, which offer ideal characteristics for this purpose[5]. Given these favourable conditions, the additional investment required to comply with IMO specifications is limited to $4 billion in the Europe region only. However, in the less favourable hypothesis of a European supply structure identical to that seen in 2005, Europe builds more fuel oil desulphurisation/conversion units, bringing this additional investment to approximately $10 billion. These latter results concur with those of a study conducted in 2010 by Concawe ($14 billion)[6]. They illustrate the significant impact on low-sulphur fuel oil production of the quality of crude refined and, more particularly, that of the residual fraction. Optimally, fuels with 0.5% sulphur content are constituted principally of a blend of non-desulphurised residual fractions (like West African crudes) and desulphurised fractions (from other crudes), whilst fuels with 0.1% sulphur content make very extensive use of desulphurised vacuum distillates. In practical terms, these formulations are much more economical than recourse to "diesel" type products (like DMA).

An unavoidable decline in mature regions refinery capacity

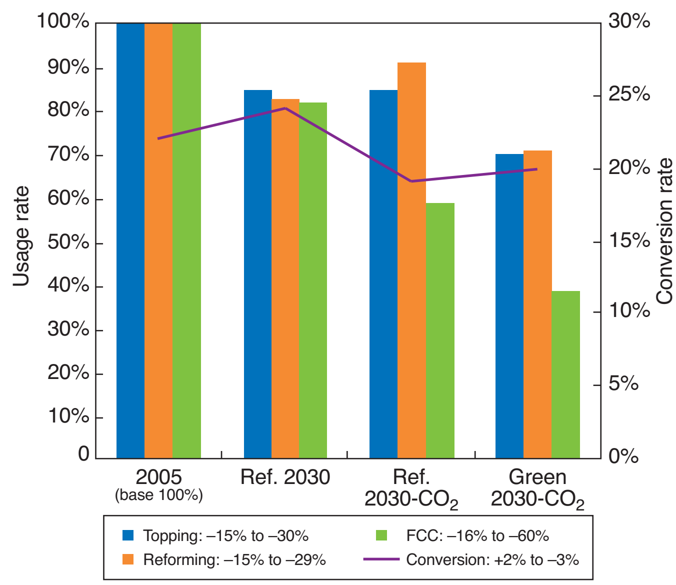
In the reference scenario, adapting the European refining base to cope with the fall in demand results in a 13% reduction in distillation (Figure 2). The investments made enable an increase in conversion to meet structural changes in demand. At like-for-like demand, application of the CO_2 penalty reduces production rates in those units generating the highest levels of emissions (FCC production 40% lower than the reference) or investment in conversion (residue hydrocracking). These results are even more marked in the green scenario, where European primary distillation and FCC decline by 30% and 60% relative to the reference scenario.

This underlying downward trend in refining capacity, both in Europe (–15% to –30%, depending on scenario) and the USA, rather confirms recent press reports of refinery closures.

(5) Characterized simultaneously by high diesel output and very low sulphur content of the residual fraction, which enables the production of IMO-compliant fuels at lower cost

(6) In 2010, Concawe and IFPEN together conducted a study on behalf of the DG Energy of the European Commission. The similarity of expenditure highlighted here refers to similar scenarios (and specifically a European diesel balance based on 40 Mt imported from the Commonwealth of Independent States (CIS))

Fig. 2 – Trend in the rate of European refinery utilization and conversion



Source: IFPEN

Impact of the CO_2 penalty

In the absence of the CO_2 penalty, the reduction of refining activity in the North American and European regions implies a reduction in the associated CO_2 emissions[7] of 8% and 17% respectively between 2005 and 2030 (to be compared with the quotas set out in phase 3 of the ETS Directive). But at global level, they reach 855 Mt/yr in 2030, reflecting an increase 29% higher than that for oil consumption itself (+22%), as a result of the explosion in capacity for upgrading of extra-heavy crudes, which emits high levels of CO_2 (in the supposed absence here of the CCS).

Applying a CO_2 penalty solely to mature refining regions amplifies the effects of lower domestic demand for European and North American refineries between 2005 and 2030. Being less competitive, they are encouraged to relocate part of their sourcing of oil products to the emerging countries or the CIS (the leakage effect, which is also a possibility within the ETS bidding mechanism). This transfer of activity automatically results in a 10% reduction in CO_2 emissions by Europe/North America (–16% and –7% respectively) to a total of 32 Mt/yr of CO_2 relative to the reference. Nevertheless, at global level, this has only a minor impact on overall emissions, which total 843 Mt/yr, reflecting a –1.5% reduction relative to the reference.

In this context, the CO_2 emission reductions in North America and Europe are achieved by adjusting refining capacity (–1% relative to the reference), the fall in conversion rates (–3% and –5% respectively) resulting from the reduction in FCC capacity (–20% and –30%), and

(7) Refining and upgrading of extra-heavy crudes

recourse to lighter crudes (+1.1 and +2.7 API). More marked in Europe, this latter influence paradoxically leads to higher exports of gasoline to North America from Europe, despite the reduction in conversion rates (below the global average). The resulting reduction in diesel output is offset in Europe by major recourse to imports of Russian diesel (60 Mt/yr instead of 46 Mt/yr, reflecting a 30% increase). The level of investment is also reduced to $13 billion (–$9 billion). European refining therefore uses external trade to adapt to its market.

Lastly, the application of a standard global CO_2 tax has no significant effect, either on overall emissions (829 Mt/yr, or just –3% relative to the reference scenario), or on refining itself (type and location of investment, international product trading, etc.). This is largely the result of the fact that no technological innovation in terms of refinery process and/or utility energy efficiency has been considered.

Conclusions

The principal medium-term and long-term changes likely to be experienced by the refining industry in general, and the European industry in particular, in response to the major energy trends presented in this study are as follows:

- a reduction in refining capacity in Europe and North America. Reflecting the fall in their consumption of fuels, this reduction is the outcome of new regulations applied to new vehicle emissions, and the introduction of biofuels. This trend therefore raises doubts about the continued operation of the least productive refineries in these regions;
- a shift in refining investment to Asia, the Middle East and South America. Refining is moving towards the emerging countries (where demand for refined products is high) and the leading crude oil producing countries;
- a continued mismatch between refining and the structure of demand in Europe. Europe's gasoline surplus could continue to meet part of American demand, with net imports of diesel from the CIS to make good its shortfall in supply. However, other geographic regions (principally the Middle East and Africa) could compete with European gasoline exports, hence the major question mark raised over the long-term future of this export market;
- a significant impact imposed by CO_2 emissions quotas in Europe (and in the USA, if such quotas are introduced there). This constraint, which is modeled in the form of a "flat rate tax" applied to these two regions only, results in CO_2 leakage to those regions where it is not applied, without reducing overall emissions for the industry at global level;
- the structural character of future global specifications governing the sulphur content of bunker fuel oils, and its implications for the future of refining as a result of the high level of costs generated.

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