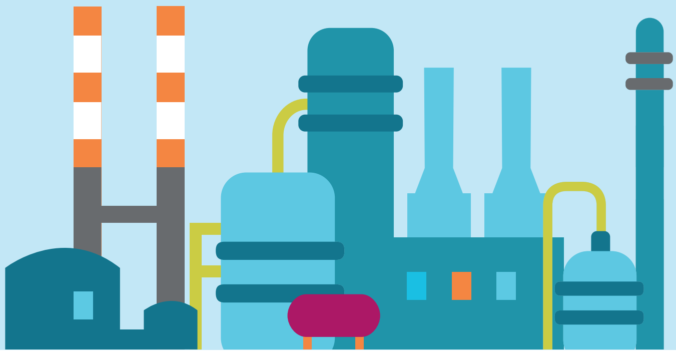
Technical Newsletter

#34 - November 2016



PETROLEUM REFINING AND INSURANCE

PART I

Crude Oil Refining - a constantly evolving industry

Introduction

Refining can be considered by many as a mature and stable industry but it has changed drastically since the 19th century, adapting to its ever-changing and challenging environment. Insurers have had to follow this transformation and adapt their way of underwriting these risks.

Part I of this Technical Newsletter takes us on the journey the refining industry has had to travel.

In the beginning was the crude oil…

Of interest to refiners and insurers is that petroleum has been known and used in various ways (adhesives, flaming projectiles, boat coating, lighting…), since ancient times. The first users of petroleum were located in the Middle East (Egypt, Babylon, Mesopotamia, Persia…) and China.

Many types of crude oils are produced around the world. The main components, primarily hydrocarbons, can be differentiated by their properties, the most important of which is the boiling temperature as it allows for the primary separation by distillation (see figure 2).

The price of a particular crude oil depends on its characteristics, two of the most important of which are density and sulfur content. Density ranges from light to heavy, while sulfur content goes from sweet (low sulfur) to sour (up to 6% sulfur). The density and concentration of contaminants such as sulfur are good indicators of how easy to process the crude is and of its price. The most well-known references for crude oil prices are Brent (North Sea) and West Texas Intermediate (WTI) however over 150 crudes are traded.

Did you know?

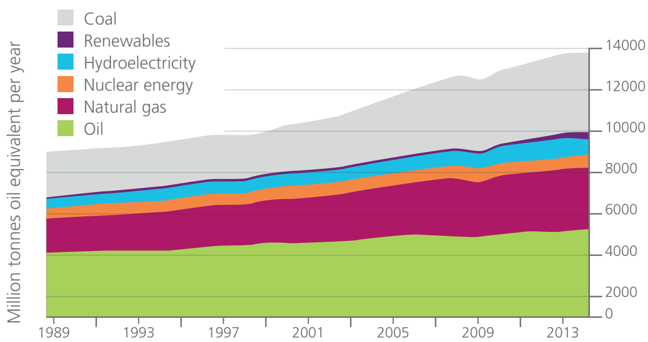
Barrel comes from the French Baril. Before it became standard in 1860 during the Pennsylvnia oil rush the 42 Gallon (159 liters) barrels were first used for petroleum in Pechelbronn, Alsace where the first oil sands were mined and refined from 1745.

"GET UP EARLY, WORK LATE - AND STRIKE OIL." JOHN D. ROCKEFELLER'S RECIPE FOR SUCCESS.

Sulfur and TAN[1] are good indicators of potential corrosion problems and are therefore of interest to insurers.

Today oil is still the primary source of energy with 32% vs 30% for coal and 24% for gas according to the BP statistical review 2015 (see figure 1).

Figure 1: World Energy Consumption



Source: BP Statistical Review 2015

[1] Total Acid Number which is a measurement of acidity

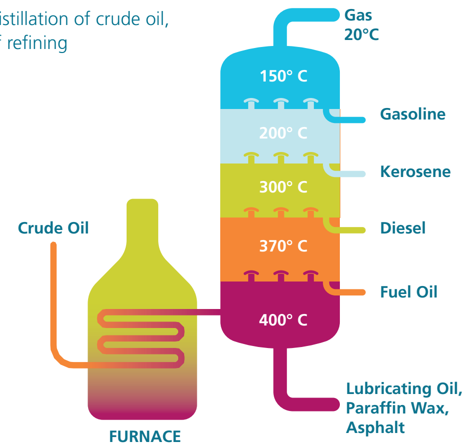
SCOR Global P&C

Refining 1.01

A petroleum refinery is an industrial process plant where crude oil is processed into more useful products such as (by order of volumes produced):

- Transportation fuels (gasoline, kerosene, diesel)
- Heating fuels (fuel oil)
- Petrochemical industry feedstocks (naphtha, propylene)
- Liquefied Petroleum Gas (butane, propane)
- Lubricants
- Bitumen
- Coke
- Sulfur

Figure 2: Distillation of crude oil, first step of refining



Source: SCOR

Basically crude oil undergoes physical and chemical processes. Figure 3 shows a typical refinery process flow diagram with usual process units and final products. **By nature, hydrocarbons are flammable products and they are processed at high temperatures and pressures in the presence of hydrogen, which exacerbates their flammability and explosivity. Hence, the safe operation of refineries requires a broad range of highly trained and specialised personnel (instrumentation, electrical, mechanical, process, safety...).**

Refinery capacity is defined by the crude throughput and is generally expressed in barrels per day (bpd). Refineries operate continuously, 24 hours a day, 365 days a year, except when they are shut down for the general maintenance of the units known as turnaround. These take place every 4 to 5 years, usually lasting 5 to 6 weeks, during which time maintenance activities that cannot be performed during normal operations are carried out.

> "TURNAROUNDS AND OTHER MAINTENANCE ACTIVITIES ARE IMPORTANT FOR THE INTEGRITY OF THE PLANT AND THEREFORE OF PARTICULAR INTEREST TO INSURERS."

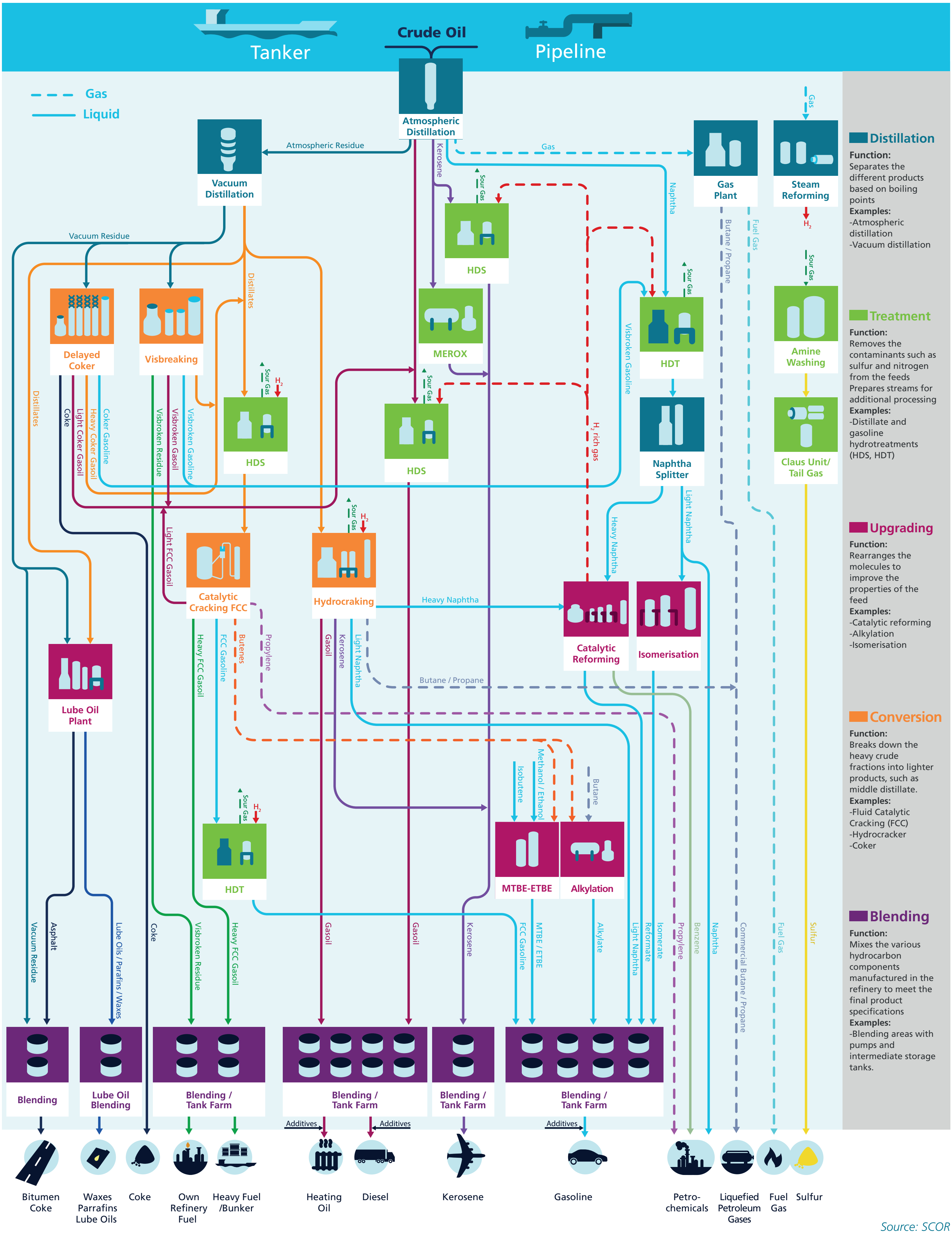
Due to the evolution of technology and automation, the number of employees has decreased from several thousands, for example the Whiting Refinery in the US employed 3000 people in the early 1900's, to a few hundred in developed countries depending on the level of contracting. In some cases, the number of employees could be higher, as it can be used by governments as a means of employment. The skills of the employees have significantly changed and the level of knowledge has increased considerably.

Finally, the complexity of refinery operations is such that they can be fully optimised to produce the highest possible margins, only through the use of Linear Programming (LP) models to respond to changes in market environment and to the introduction of new (usually more stringent) product specifications and new crude slates.

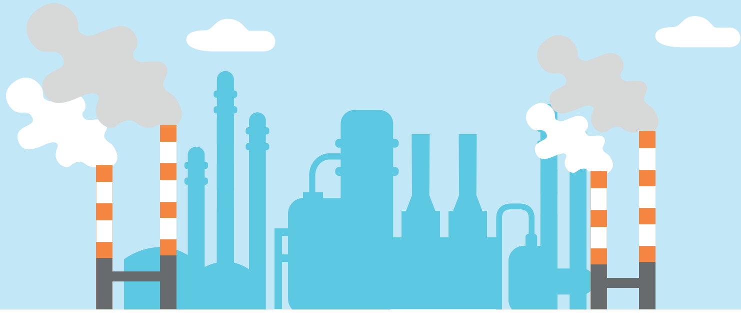
Refineries are composed of three main areas:

- **PROCESS UNITS:** where crude oil is actually transformed into final products.
- **UTILITIES:** produce all the utilities required by the process units such as power, steam, hydrogen, nitrogen, air, water…
- **STORAGE (feedstocks and products):** required to store the crude oil and final products before they are expedited.

Figure 3: Refinery process flow diagram



Source: SCOR



The complexity of refining processes has been increasing dramatically

The refinery process has been improved over more than 100 years with the addition of new, more complex units.

The Nelson Complexity Index (NCI), which allows to measure the conversion capacity in comparison to the primary distillation capacity of any refinery, is used to compare refineries. It is an indicator of the investment intensity or cost index of the refinery but also the potential value added of a refinery (see table 1).

The trend of increasing conversion capability will pull up the complexity index as the world's demand for lighter products increases.

The complexity index has increased over the years (see figure 4).

Table 1: From simple to complex refineries

CONFIGURATION	NELSON COMPLEXITY INDEX	DESCRIPTION
Topping	< 2	This type of refinery simply separates crude oil into light gas, refinery fuel, naphtha and distillates (final products) by atmospheric distillation. There are no chemical reactions involved.
Hydroskimming	2-6	Upgrades naphtha into gasoline with catalytic reforming and removes sulfur with hydrotreating units.
Conversion	6-12	Converts heavy crude oil fractions (fuel oil, asphalt low value product) into lighter products (such as gasoline and diesel).
Deep Conversion	>12	Converts the heaviest and least valuable crude oil fractions (residual oil) into lighter more valuable products.

A short history of the petroleum and refining industry

The modern history of petroleum started when James Oakes discovered how to produce kerosene from coal in 1847 in England.

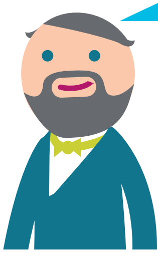
In 1857, Michael Dietz invented a flat-wick kerosene lamp that replaced whale oil and created a new market for crude oil.

The advancement of crude oil production began when Colonel Edwin L. Drake developed a new technology to extract oil from the ground near Titusville, Pennsylvania, using drilling, with a steam engine, through a pipe. The first drop of oil came out from the ground when the well depth reached 69ft, on Monday 29th August 1858, later producing 30 barrels per day. This marked the beginning of the Pennsylvania oil rush.

The conjunction of those events triggered the oil and then the refining industry boom. In 1860-1861, seven refineries were built in Pennsylvania and Arkansas. By the end of the 1860s, 58 refineries were in operation in Pittsburgh, primarily to recover kerosene.

In 1870, the US were the largest oil exporter and J. D Rockefeller founded the Standard Oil Company which by 1879 controlled 90% of US refining capacity.

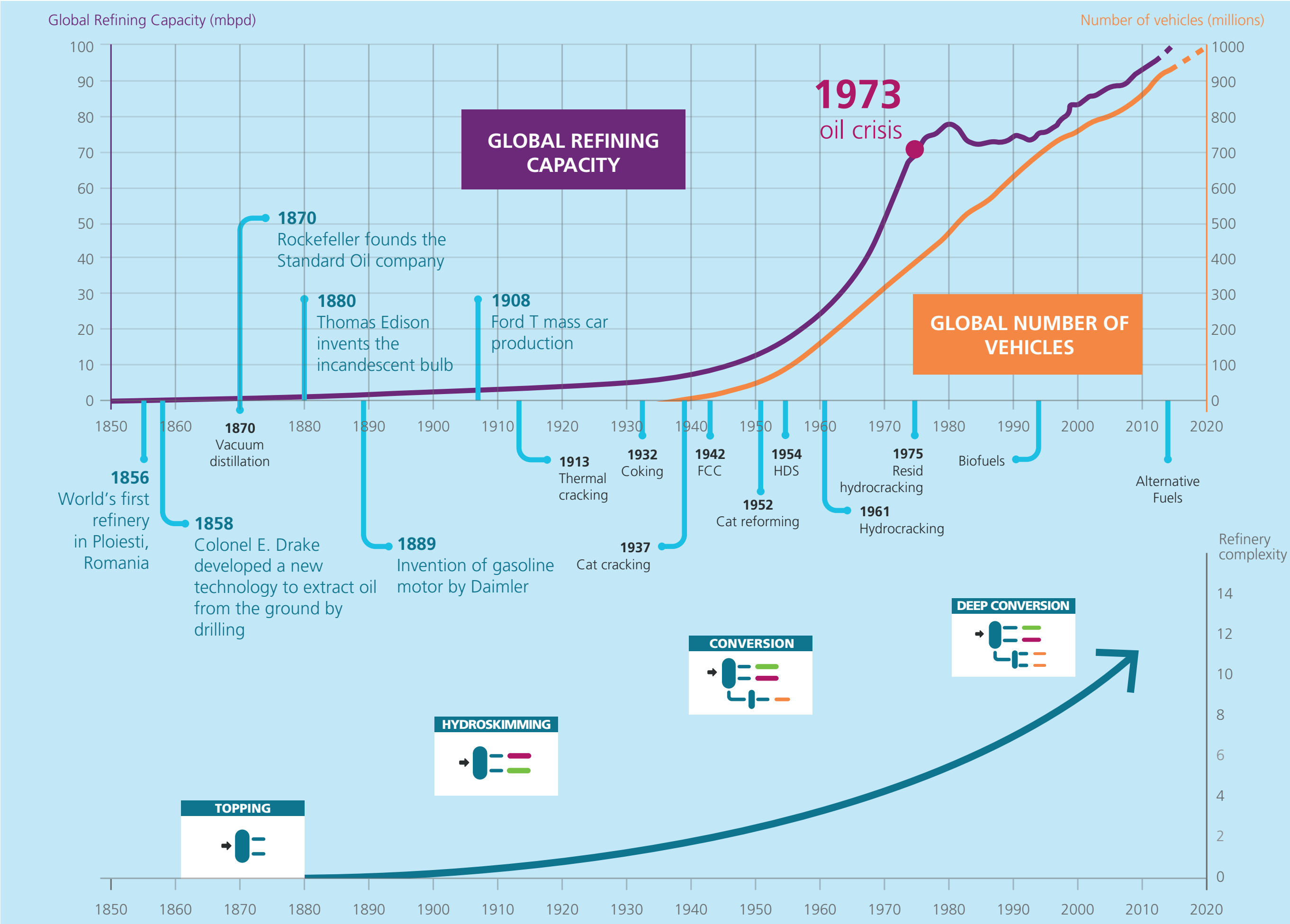
The demand for petroleum was relatively stable until the early 20th century. The invention of electricity progressively replaced kerosene lamps. The invention of the automobile and its mass production shifted the demand to gasoline and diesel.



Did you know?

Colonel Drake was to end up as an impoverished man. Pennsylvania voted an annuity of $1,500 to the "crazy man" whose determination founded the oil industry.

Figure 4: Worlwide refining since the middle of 19th century



Source: SCOR

The geography of refining now and its eastward shift

Most countries have at least one refinery. Refineries are often located on the coast. There are around **700** operating refineries[2] in the world, ranging from 10 to 1240 kbpd, with a worldwide capacity of **96.5** mbpd (according to the BP statistical review 2015). Asia has the largest refining capacity of **33.1** mbpd. The US follows with **17.8** mbpd. In counting refineries, idle refineries have not been taken into account nor have refineries that have been converted into terminals. There have been a few of these in the past years especially in Europe (Reichstett ex-Petroplus in France, Wilhelmshaven ex-Conoco in Germany, Cremona Tamoil in Italy). The 10 largest refineries in the world are indicated in table 2 on the next page.

Due to market conditions, new (or expansions of) refineries in Europe and the US are very unlikely. They are more likely in Asia and in emerging countries where there is more economic growth (see figure 5 on the next page).

"REFINERIES IN THE US AND EUROPE ARE AGEING AND NEED INVESTMENT: A POTENTIAL CONCERN FOR INSURERS."

[2] Upgraders, especially in Canada, have been excluded from the refinery count although processes are similar to refineries.

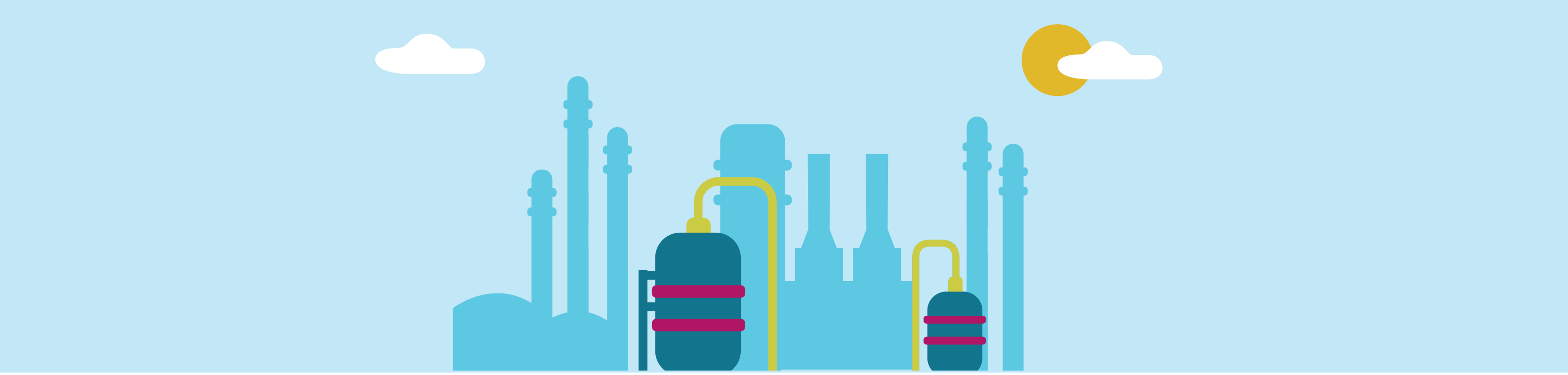


Table 2: Largest refineries in the world

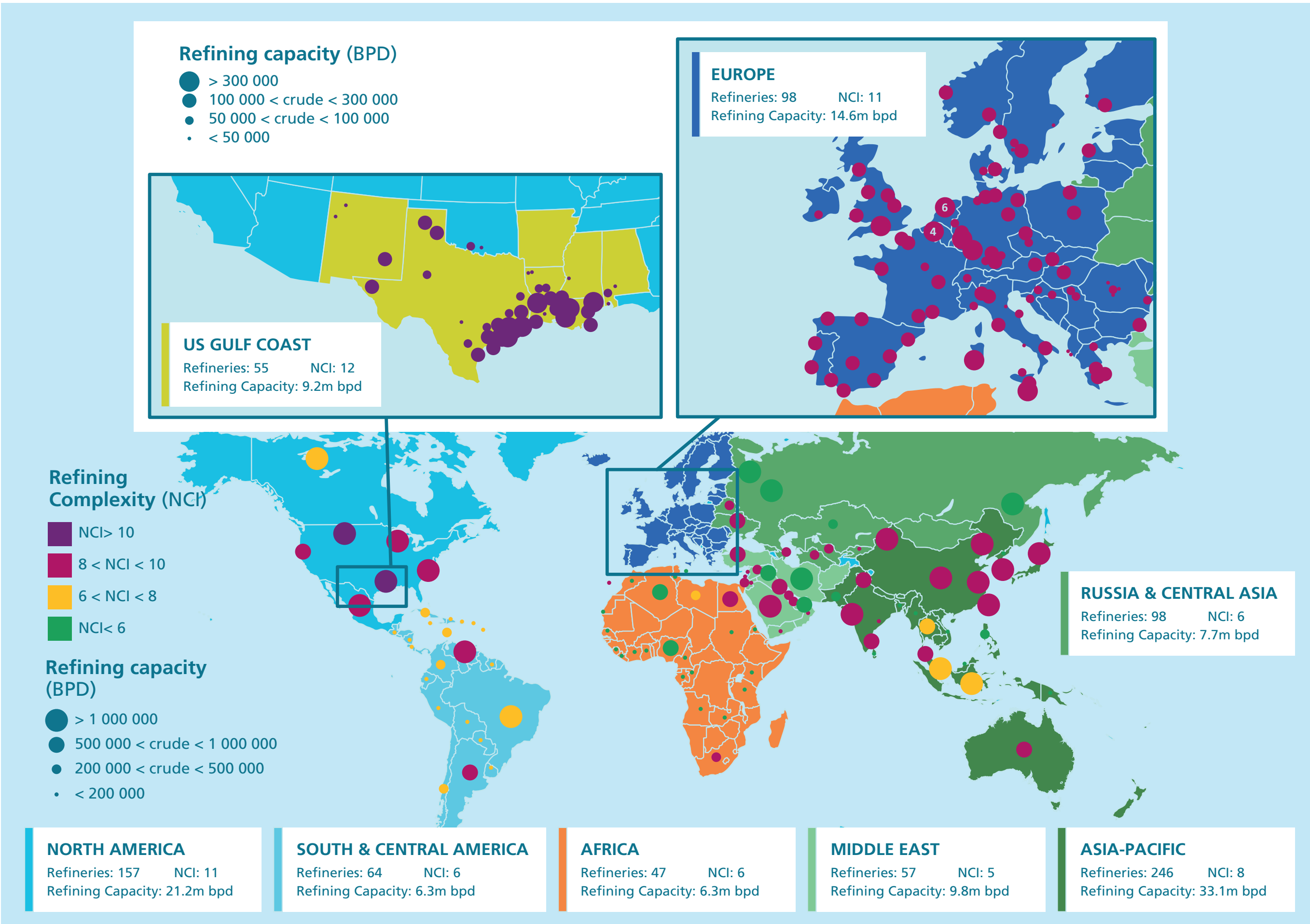
COMPANY	Reliance Industries	PDVSA	SK Energy	GS Caltex	S-Oil	Motiva Enterprises	ExxonMobil	ExxonMobil	Saudi Aramco	Royal Dutch Shell
LOCATION	Jamnagar, India	Paraguana, Venezuela	Ulsan, South Korea	Yeosu, South Korea	Ulsan, South Korea	Port Arthur, Texas, USA	Singapore	Baytown, TX, USA	Ras Tanura Saudi Arabia	Pernis, The Netherlands
CAPACITY (KBPD)	1,240	940	850	775	669	600	592	560	550	416

Source: SCOR

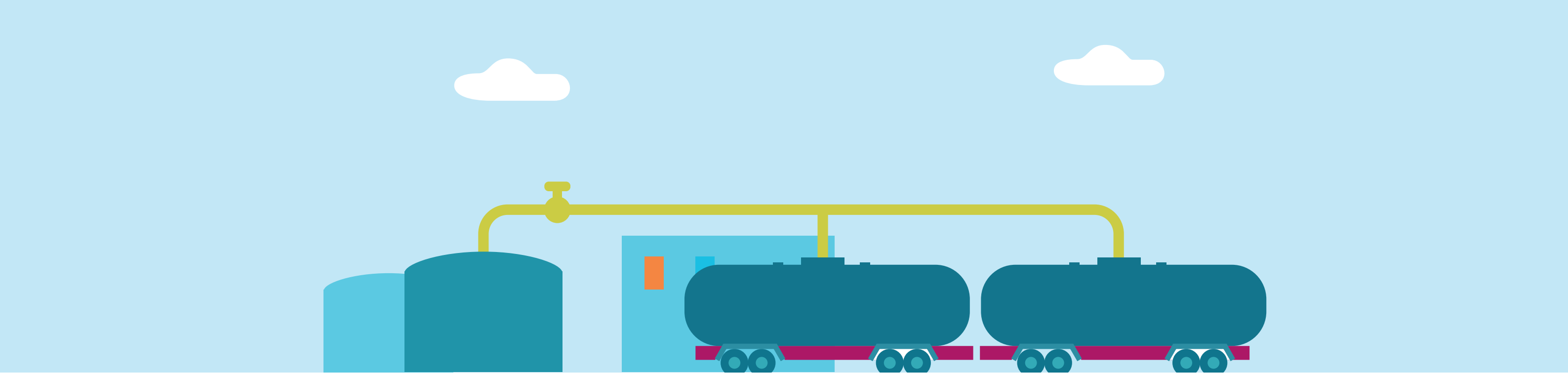
Europe has lost 20 refineries between 2007 and 2014 and the refining capacity has reduced by 20%.

New and recent refineries are large and complex, mostly located in Asia and Middle-East.

Figure 5: Global map of refineries (in 2016)



Source: SCOR



Refining has been evolving in recent decades due to external constraints

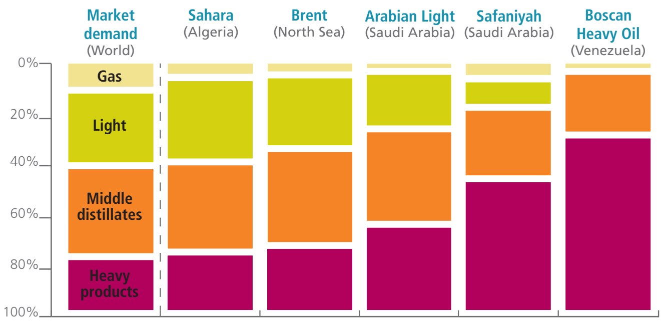
Refining has had to adapt to 3 main external constraints on refineries themselves and on finished products.

Refineries have been increasing their conversion rates to adapt to heavier crudes

In many manufacturing industries such as car, electronics, chemicals... raw materials have tight specifications to produce very specific and identical products, whereas refineries adapt to different crudes and optimise operating conditions to achieve varying product yields, as per figure 6.

"HEAVY CRUDES HAVE PROPERTIES DIFFERENT FROM "CONVENTIONAL" CRUDES (CONTAMINANTS, DENSITY…) THAT BRING NEW CHALLENGES INCLUDING CORROSION, TO REFINERS AND THEIR INSURERS."

Figure 6: Crude yields vary considerably



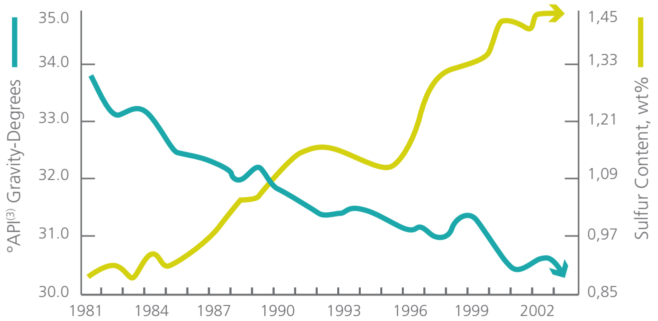
	Sahara	Brent	Arabian Light	Safaniyah	Boscan
Density	0,806	0,837	0,855	0,893	0,995
°API[3]	44	37,5	34	27	10,7
Sulfur content Wt %	0,2	0,3	1,7	2,8	5,3

Source: SCOR

With the development of oil fields worldwide, the crude slate has been changing over the past decades, becoming heavier and containing more contaminants, such as sulfur, as per figure 7.

New sources of oil have also become available: shale oil and oil sands.

Figure 7: Sulfur up, °API[3] down



Source: IEA

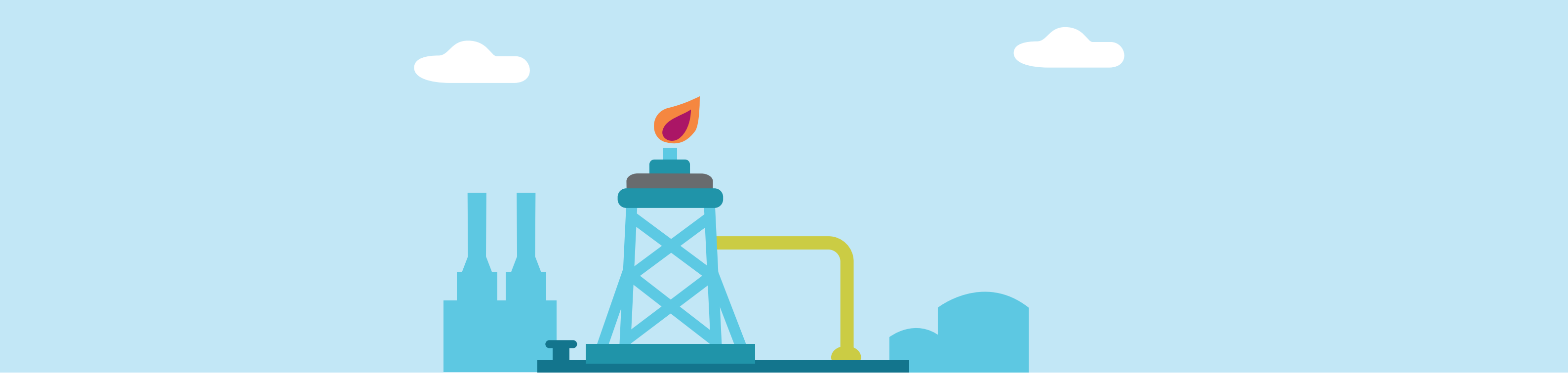
Consequently, refiners have had to invent new technologies to increase conversion, to be able to produce the same volumes of refined products.

Product demand has been changing, thus requiring refineries to adapt.

Generally speaking, the product slate (gasoline, diesel...) obtained by simple distillation of any crude oil does not meet the market demand in terms of volume, nor in terms of properties.

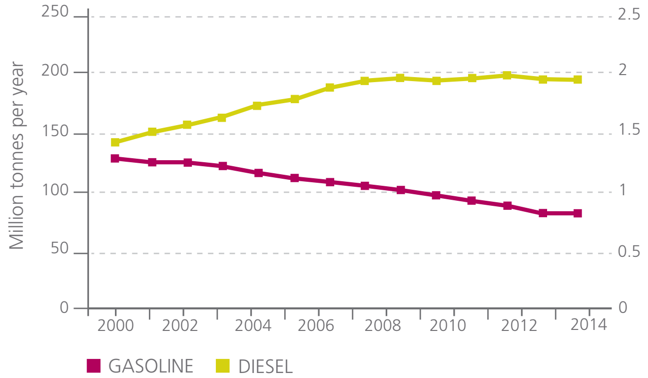
In order to meet the specifications required by the end users, refinery schemes have added new "upgrading units", such as in the 60s-70s, reforming units to produce premium gasoline.

[3] °API gravity is an inverse measure of density.



The demand for finished products has evolved towards more diesel engines in Europe (see figure 8). This has been leading to a structural imbalance between gasoline and diesel.

Figure 8: Road fuel demand in Europe



Source: Fuels Europe

In order to be able to process a wider range of crudes and to adapt to the changing demand, refineries have to be more flexible, and need the construction of new conversion units such as FCCs, hydrocrackers and cokers.

The hydrogen challenge

The changes in the refinery configuration have led to new technical challenges for refiners. One of the most important is the increase in hydrogen consumption. Indeed, in the simple refinery scheme, hydrogen is in surplus and is produced in the reforming units. But with new conversion units, particularly hydrocrackers and hydrotreatments, requiring hydrogen in large quantities, new hydrogen production capacities have been required and new units have had to be built.

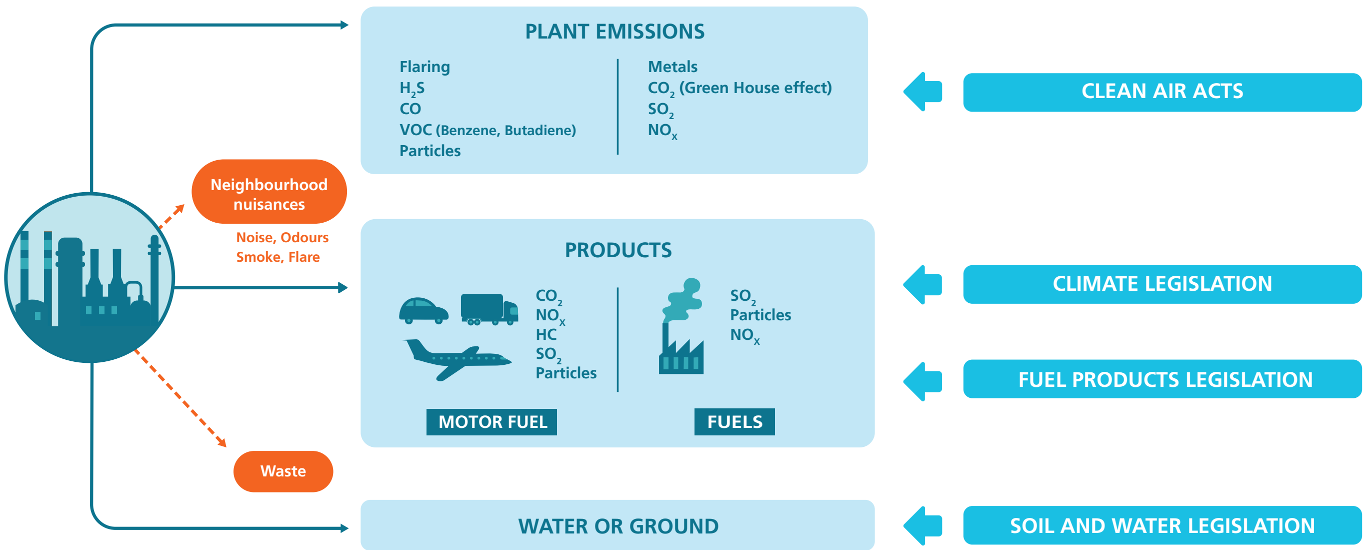
Environmental legislations have been increasingly constraining on refineries and their products

Refineries generate a lot of emissions in the environment, which have been increasingly controlled by a lot of new regulations, adding new constraints on the production tool (see figure 9).

In addition, finished products have had to become "green(er)" adding another constraint on refineries.

Different legislations in the US (California Air Resources Board, Environmental Protection Agency) and in Europe (European Commission) were passed imposing new product specifications to protect the environment (from acid rains, for example), to improve the air quality, and public health. These continuous regulation changes and emission control have led to significant changes in the refinery configuration, as illustrated in table 3.

Figure 9: New regulations that affect refineries.



Source: SCOR

Table 3: Refinery responses to regulation changes

YEAR	TITLE	REGULATION'S AIM	SPECIFICATIONS	REFINERY RESPONSES
1970s	Lead Phase Out	To remove lead additives from gasoline due to their toxicity	Lead, used as an octane booster, is prohibited in gasoline	New reforming / isomerisation units to boost octane
1990s	Addition of oxygenates	To reduce air pollutants such as CO, NOx, PM (particulates), VOCs (volatile organic compounds)	US: min 2 wt% oxygen content in gasoline EU: max 3.7 wt% oxygen content in gasoline	Incorporation of alcohols (methanol, ethanol) or ethers (MTBE, ETBE). New MTBE or ETBE units
2000s	Benzene reduction	To reduce the benzene content in gasoline as benzene is carcinogenic	US: benzene content max 0,62 vol% EU: benzene content max 1 vol%	New Benzene splitters or Benzene hydrogenation units
2000s	Sulfur reduction	To reduce SO_2 emissions	Sulfur in gasoline (max) US: 2006: 30 ppm from 2017: 10 ppm EU: 2009: 10 ppm (EURO V)	New hydrotreatment units to remove sulfur from gasoline and diesel, with specific levels
2010s	Marine Fuel Legislation	To reduce the emissions of ships in some EU areas	EU: max sulfur content 0.10% in bunker fuel oil for ships in the Baltic, the North Sea and the English Channel	Reduction of fuel oil production by addition of new conversion units

The impact of those regulations on car emissions have been substantial. Similar legislation trends can be observed worldwide. It started in the developed countries (Europe, Japan and the USA) and now most of emerging countries in Asia, Africa and South America have started to adopt legislations on emission standards. These specifications are likely to be even tighter in the future. Refineries will have to continue to invest to meet these new requirements.

Greenhouse Gas (GHG) emission reduction

In the last 20 years, the effects of greenhouse gases (such as CO_2) on global warming have been demonstrated.

The United Nations has addressed it with the UNFCCC (United Nations Framework Convention on Climate Change) which is the parent treaty of the Kyoto Protocol signed in 1997. It established a commitment for the 196 State Parties to reduce their greenhouse gas (GHG) emissions.
The Conference of Parties (COP), which is composed of all state parties, meets annually at world conferences and checks the successful implementation of the objectives of the Convention.

The main objective of COP21 (the 21st session) held in Paris in December 2015 was to achieve an agreement on climate in order to maintain global warming below 2°C. To reach this target, GHG emissions will need to be reduced by 40-70% by 2050.

Several options are available to achieve this through the use of biofuels, lower GHG fuels (natural gas, LPG), energy efficiency, carbon capture and storage (CCS)...

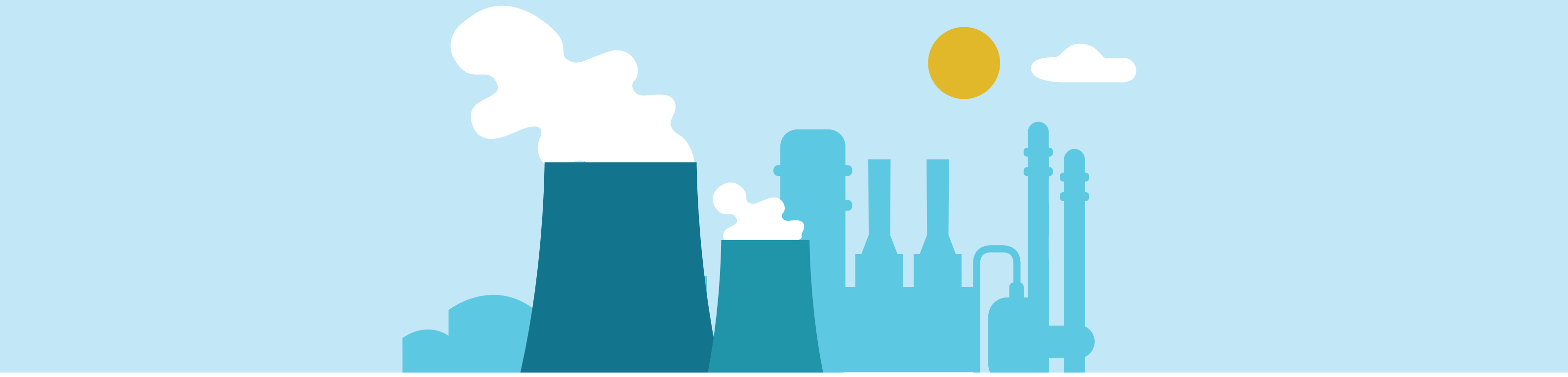
Three of them are further developed in this newsletter:

Refineries have to increase their energy efficiency to reduce GHG emissions

Refineries need to burn large quantities of fuel to generate heat and power. To meet their requirements, refineries have many large furnaces. They are important contributors to the GHG emissions. So tighter regulations (on sulfur), and the need for conversion units have actually increased CO_2 emissions of refineries (red curve of figure 10).

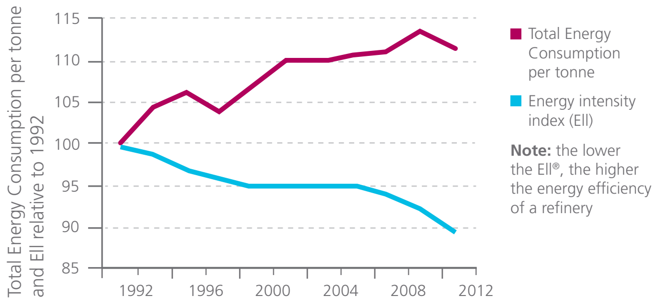
In order to meet their targets in terms of reduction of GHG emissions, refineries have had to reduce the energy required (see figure 10) to operate the units and several options are available:

- Heat recovery improvement by installing more efficient heat exchangers
- Optimisation of operating conditions through new advanced process controls in order to reduce the energy consumption



- Use of more efficient technologies:
    - Catalysts operating at lower temperatures, hence reducing the energy consumption
    - Distillation columns with high efficiency trays
    - High efficiency burners for fired heaters
    - Cogeneration plants
- Hydrogen management (Hydrogen recovery in purges, new dedicated hydrogen production units)
- Optimisation of utilities (steam production and recovery, flaring reduction).

Figure 10: EU refineries' energy intensity index

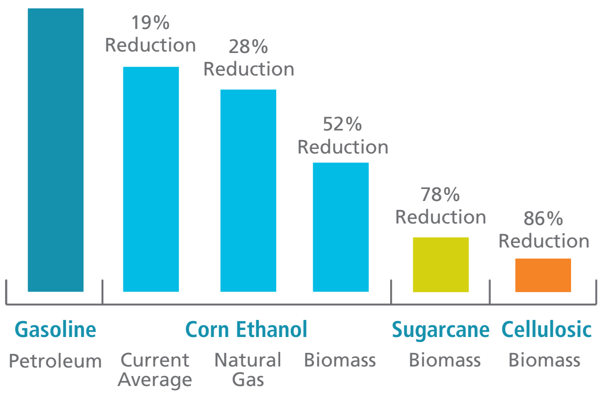


Source: Solomon associates

Renewable fuels production has to increase, to reduce GHG emissions

Different studies have demonstrated that the use of renewable fuels is an efficient way of reducing the carbon footprint (refer to figure 11).

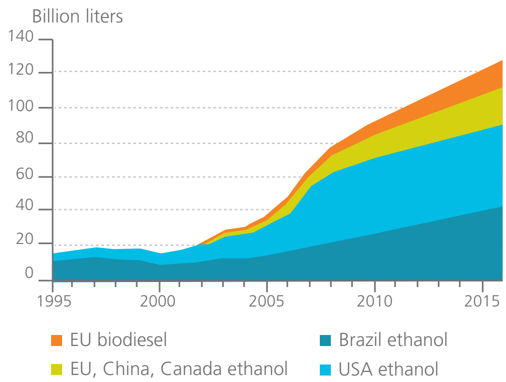
Figure 11: Greenhouse Gas Emissions of transportation fuels by type of energy



Source: Alternative fuel data centre, US department of Energy

Several legislations have imposed the incorporation of biodiesel and ethanol in fuels. As a result the addition of biofuels has been increasing over the past 10 years (see figure 12).

Figure 12: Global biofuel production 1995-2015



Source: IEA

As of today, most of the biofuels used are obtained from edible materials (i.e. vegetable oils and sugars) and are called "conventional biofuels".

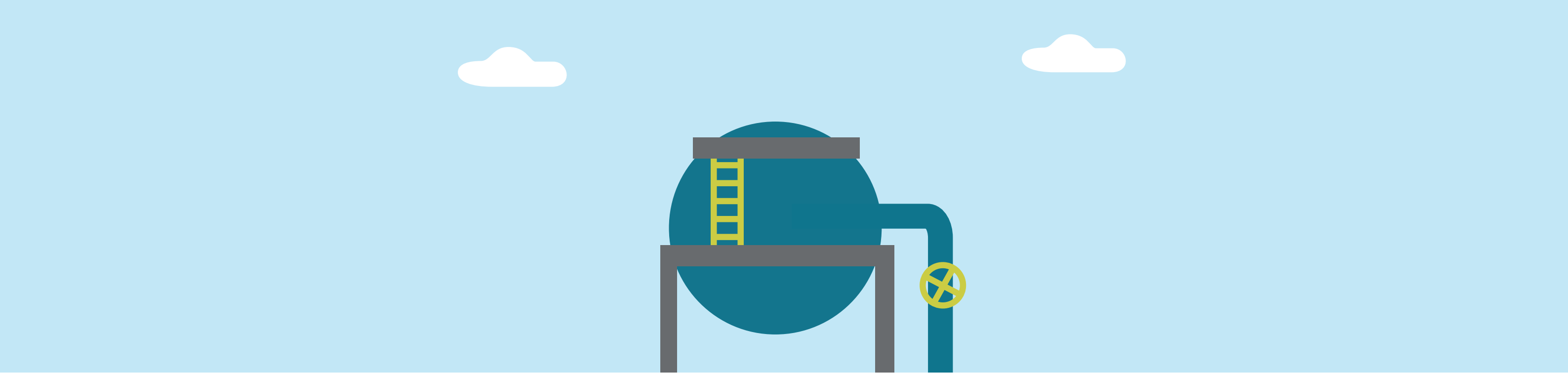
However, this situation is not sustainable on a long term basis, as it enters in competition with the use of land for food.

To address this point, the European Parliament adopted an EU Council text that limits the amount of food crop-generated biofuels by 2020, with a cap set at no more than 7% of transport's energy consumption.

This binding legislation encourages the development of biofuels produced from non-edible materials (see page 11 for more details), wich are called "advanced biofuels".

Did you know?

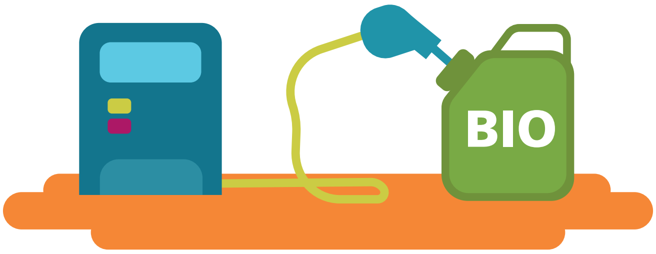
- In 2015 in most countries, the gasoline used in cars contained up to 15% bio-ethanol. In Brazil, this goes up to 25% and most cars are equipped with flex fuel engines able to run on 100% bio-ethanol made mainly from sugar cane.
- In the US, the Renewable Fuel Standard (RFS) requires that transportation fuel contains a minimum volume of renewable fuels to limit the GHG emissions. The volume of blended renewable fuels has to be multiplied by 4 from 2008 to 2022; in other words an annual growth rate of 10%.



What are biofuels?

Biofuels (bioethanol in gasoline and biodiesel in diesel) technologies fall into three main categories depending on the raw materials they use.

- The 1st generation of biofuels uses edible materials obtained from wheat, corn, sugar cane, palm oil also used for feeding humans. These are called conventional biofuel technologies. They are well proven and are producing biofuels on a commercial scale, such as in Brazil, the USA…
- The 2nd generation of biofuels uses non edible materials, obtained from dedicated rapid growth crops (jatropha, wood, straw, dry agricultural residues) to produce bioethanol or animal fat and vegetable oils to produce biodiesel. These technologies are under development (R&D or pilot stage), with few exceptions at an early commercial stage.
- The 3rd generation of biofuels uses materials not obtained from soils, such as algae. These technologies are very promising, as the feedstock is available in very large quantities, but they are under R&D stage and will not be available for several years.

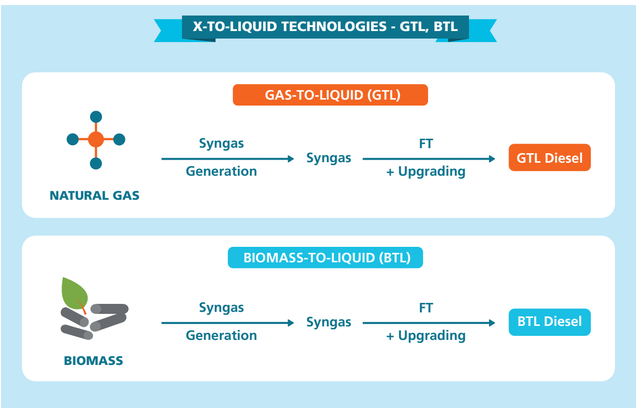


Production of alternative fuels will have to increase to reduce GHGs.

Along with renewable fuels, the reduction of GHGs can be achieved by developing alternative fuels that are less carbon intensive.

Alternative liquid fuels can be produced from various sources: Gas or Biomass. In most cases, the first step is to produce syngas (hydrogen + carbon monoxide) by various processes, which is then converted into liquid (mainly diesel) through the so-called Fisher Tropsch (FT) process (refer to figure 13).

Figure 13: X-to-liquid technologies - GTL, BTL.



Source: Axens

> "LIQUID FUELS OBTAINED FROM BIOMASS OR GAS CAN SIGNIFICANTLY REDUCE CO_2 EMISSIONS COMPARED TO CONVENTIONAL LIQUID FUELS."

These technologies have not been utilised on a wide-scale, as only five gas-to-liquid (GTL) plants are currently in commercial operation. GTL plants are located in countries where natural gas is abundant such as Qatar and Nigeria.

Pearl GTL, located in Qatar, is the world's largest GTL plant. It has a capacity of 140 kbpd and was started up in 2011.

The diesel produced from biomass-to-liquid (BTL) generates 86% less CO_2 emission per km, according to a study carried out by Concawe in 2006.

No commercial-scale biomass-to-liquid (BTL) complex has been installed yet.

Global P&C

In the top 4 for process innovation

According to data presented by the European Commission in its annual competitive report, the refining industry was the leading industrial sector in process innovation and among the top 4 for product innovation. Research and Development (R&D) is a key part of refining industry, it has allowed it to deal with the challenges posed by new environmental legislations, new product specifications and to improve refining margins... One example is developed here below: catalysts.

Catalysts

Catalyst manufacturers have adressed refining contraints by developing new formulas however this often requires intensive R&D work, several years before a new catalyst is commercialised.

Catalysts are at the heart of the processes and key to the refineries' performance. As the catalyst is consumable, changing the catalyst type is an "easy way" for refiners to increase the performance of their operations.

There are 3 main R&D areas to improve refining performance:

› activity (to process more difficult crudes, i.e. higher density and higher contaminant content),

› selectivity (to produce the right products while minimising the unwanted ones),

› stability (to increase the catalyst life and minimize the number of days of unit shut-downs, with subsequent loss of production).

Did you know?

Catalysts are made of a support, usually an inert material (alumina) with a specific shape on which the active component (platinum, palladium, cobalt, nickel…) is dispersed. The metal / support combination is specific to each catalyst and is part of the "know-how" of the catalyst manufacturer.

Conclusion

By nature, the refining industry is very complex and has constantly been evolving and adapting since the 19th century. As a result, **underwriters of petroleum refining have also had to innovate** as they need to consider new technologies, changing crude oil quality and its consequences on issues such as the ageing of refineries and corrosion. These points will be further developed in Part II of this publication.

Forecasters predict an increase in global refining capacity in the coming years, which means a potential growth of insurable assets. However energy predictions are very difficult with lots of factors and uncertainties, political, societal, technical, economic…

Environmental constraints are currently aimed at moving towards a low carbon world and developing renewable energies as illustrated by the 2015 Paris agreement. This will put refineries under further pressure to improve emissions and will impose higher production levels of renewable fuels and alternatives to traditional fuels.

We are confident that refiners will manage to further adapt to tomorrow's challenges and invent new technologies. Refining in the future will be cleaner and more productive.

Michel KRENZER
Onshore Energy Manager, EMEA Team
Global Onshore Energy Practice Leader
+ 44 203 207 8633
mkrenzer@scor.com

Jean-Christophe CANDELON
Onshore Energy Underwriter
+44 203 207 8698
jcandelon@scor.com

PLEASE FEEL FREE TO VISIT US AT SCOR.COM

SCOR Global P&C
5, avenue Kléber - 75795 Paris Cedex 16
France
scorglobalpc@scor.com

Global P&C

TO GET THE FULL RANGE OF TECHNICAL NEWSLETTERS, PLEASE CONTACT SCORGLOBALPC@SCOR.COM

Editor: SCOR Global P&C Strategy & Development
ISSN: 1967-2136