TECHNICAL NEWSLETTER

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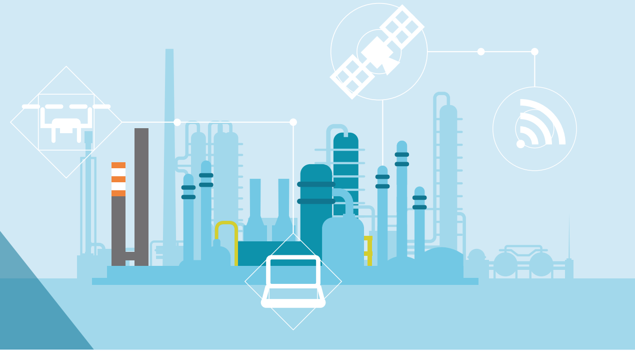


THE REFINERY OF THE FUTURE

ENERGY TRANSITION, DIGITAL TRANSFORMATION, ETC. WHY IT MATTERS TO ENERGY UNDERWRITERS… AND ALL OF US!

Like never before in their histories, petroleum companies and refineries are facing major challenges, but they are also facing opportunities.

On the one hand, demand for oil and its derivatives is predicted to grow further over the coming years, before dropping due to the energy transition, while oil products, even at a slowing pace, will still play a major role in the energy consumption mix for decades.

The Covid-19 pandemic in 2020 has caused a temporary decline in utilisation rates and margins, resulting in a wave of refinery closures or conversion to terminals or biofuel refineries. Increased working from home and reduced air travel have created some uncertainty regarding the post-Covid impact on demand for oil products, but this is likely to recover.

However, on the other hand, refineries are carbon-intensive (scope 1 and 2)[1] and the use of refining products produces large quantities of CO_2 (scope 3).[1] At the same time, dealing with climate change, growing sustainably and recycling have become priorities for our society. More than 100 countries have made commitments to reach net-zero carbon by 2050. The US re-entered the Paris agreement in January 2021. This means gigantic disruption and trillions of dollars of investments in the energy sector. How are refineries responding to this paradigm shift?

Our recent roundtables with energy risk managers have confirmed that climate change is at the top of their priorities. This raises the question: how are refining companies impacted?

Corporate pledges to reach net zero emissions by 2050 and projects directly linked to mitigating climate change are growing exponentially. On the one hand, scope 1 and 2 emissions are being dealt with by carbon capture and storage, carbon intensity reduction, plastics to oil, etc., while biofuel and hydrogen projects are tackling scope 3 emissions (these represent the largest proportion of emissions from refinery products).

In the meantime, digitalisation and smart technologies are transforming our daily lives, and industrial applications are constantly being developed, adding another challenging transformation for refineries. Artificial Intelligence (AI) will play a key role in energy efficiency gains, improving reliability, maximising mechanical availability and optimising operations. This digital transformation will have an impact on the operational risk of refineries.

Refineries are responding to these disruptions by innovating. Onshore energy insurers are adapting too, to be able to support their clients. This article will address these fundamental issues, which will shape the refineries of the future.

1. Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the generation of purchased electricity, steam, heating and cooling consumed by the reporting company. Scope 3 includes all other indirect emissions that occur in a company's value chain, including end use of products.

SCOR
The Art & Science of Risk

REFINERS HAVE ALWAYS BEEN ON THE MOVE BUT CLIMATE CHANGE IS THEIR BIGGEST EVER CHALLENGE

Let's have a look at the drivers of change, the pressures as well as the opportunities, which will influence and shape our future and the future of industrial plants, and more specifically refineries. All companies are influenced by a number of external factors, which also bring uncertainties. Figure 1 shows some of the most relevant. Some are remote, and some are proximate, but they are all interrelated.

Demographics is a driver of growth. With the global population increasing from the current 7.5 billion to 9 billion by 2040, and a growing middle class, the demand for petrochemicals is forecast to grow faster than GDP.

Competition is of course a major driver of change, particularly with over-capacity in some regions and with demand set to fall in the future as the number of electric cars rises. The abundance of oil and gas is not an issue.

Increasing pressure from **society** translates into legislation, which in turn places additional constraints on industrial plants and particularly on refineries. In the US, a number of major oil companies are being sued regarding the impact of climate change, while other countries such as China want "blue skies again".

Politics, informed by bodies dealing with environmental issues (the International Energy Agency (IEA) just published its roadmap to achieve net zero emissions by 2050[2]), plays an important role in pushing towards carbon neutrality through legislation and regulation, for example by putting a price on carbon (e.g. European ETS Emissions Trading System), subsidizing low-carbon technologies, spurring innovation, prohibiting single-use plastics, introducing climate-related disclosures, and banning internal combustion engines from 2035 in some countries. "Governments have the decisive role".[3]

Safety has always been a concern due to the handling of large amounts of flammable and combustible products, and because plants are under the scrutiny of authorities. Industrial accidents occasionally serve as reminders that these plants are inherently dangerous.

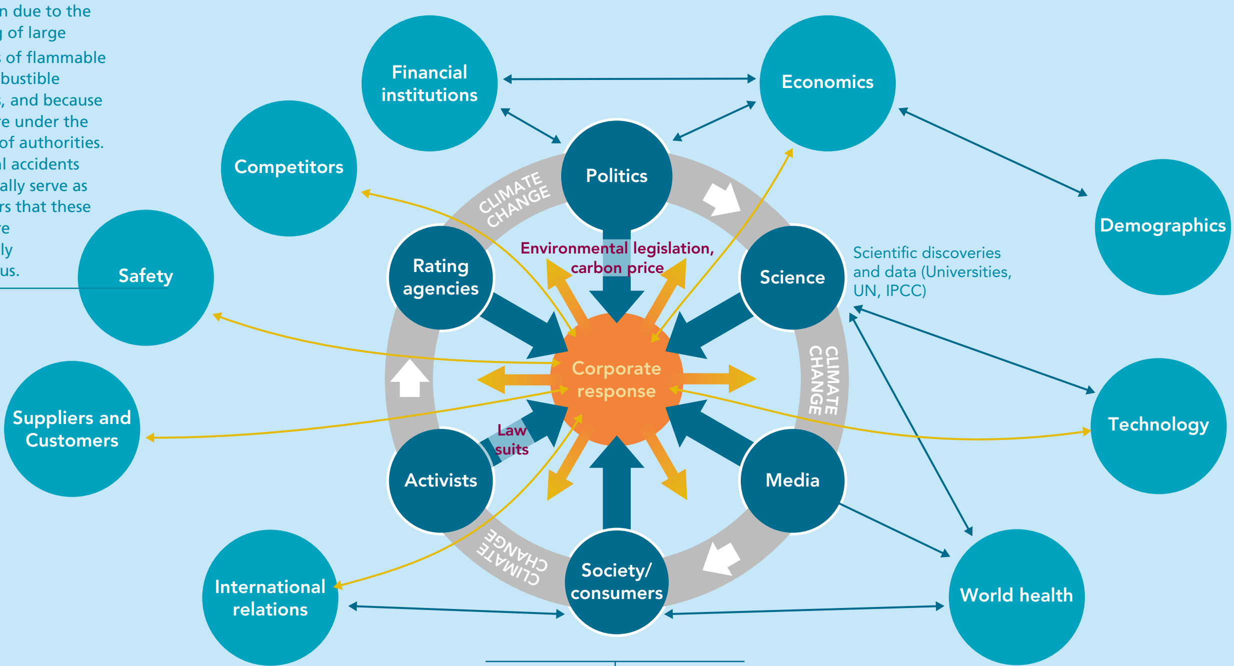
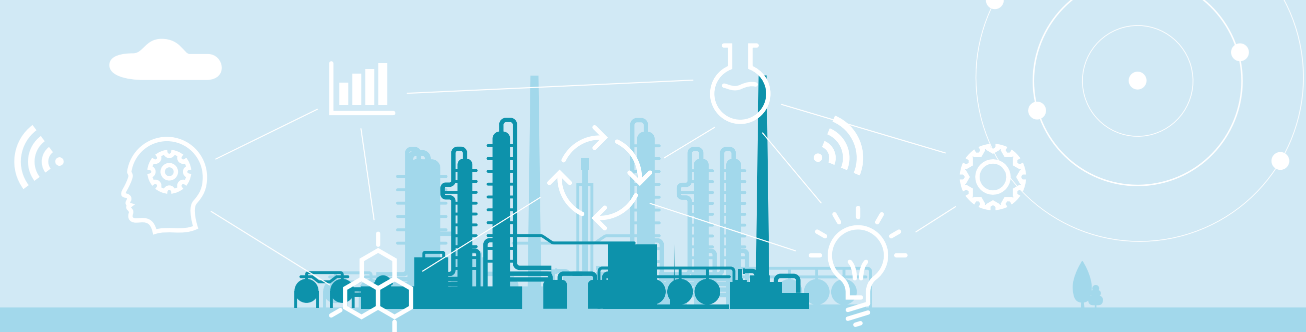


FIGURE 1: INDUSTRIAL COMPANIES ARE DRIVERS FOR CHANGE

Source: SCOR

2. *Net Zero by 2050, A roadmap for the Global Energy Sector,* IEA, May 2021 – https://www.iea.org/reports/net-zero-by-2050
3. *World Energy Outlook*, IEA,2020 – https://www.iea.org/reports/world-energy-outlook-2020



Environmental legislation has been increasingly strengthened in several industrial sectors. It is specifically important to refiners due to plant emissions, that will potentially grow due to demand, very large energy consumption (with production of GHG gases), in addition to specifications being imposed on petroleum products themselves. The ULSD (Ultra Low Sulfur Diesel) norm for example, capping sulfur content, cost refiners hundreds of millions of dollars in investment to reduce pollution produced by vehicles. Another challenge was the International Maritime Organisation's "IMO 2020" regulation, with a short deadline. Ships had to reduce their emissions by switching to marine fuels with sulfur content lower than 0.5% against the previous limit of 3.5%. Refiners provided an example of how to adapt again, with expected price reduction of high sulfur fuel and increase in the price of low sulfur diesel. Some refiners invested in new processes and new products.[4] This was also an opportunity for refiners to differentiate themselves.

Technology will affect refineries directly as we will see below, for example with more powerful equipment and new sensors. It will also have an indirect impact, causing the demand for petroleum products to fall - examples include the growth of solar and wind power, the rapid development of energy storage, and lower prices for electric cars. New CO_2 reduction technologies like Carbon Capture and Storage (CCS) will allow refineries to continue running without fundamentally changing existing processes.

REFINERIES RESPOND IN A VARIETY OF DIFFERENT WAYS TO THE HUGE CHALLENGE OF ACHIEVING NET ZERO EMISSIONS BY 2050

In their 150-year history, refiners have constantly adapted to their economic environment by inventing **new processes** or improving existing ones, which can be as simple as switching from fuel to gas as an energy source. Starting with simple distillation in the late 19th century, more sophisticated processes were then invented - such as cracking and later catalytic cracking for example.[5] This tailoring will continue with new, more efficient processes and better catalysts, reducing energy intensity for both economic and environmental reasons. In terms of new processes, several of these are currently being developed, for example to produce biofuels and to convert crude oil directly into plastics.

The second way to adapt and prosper is to create **new products,** such as products with a low carbon footprint. This is another traditional area of Research and Development or R&D, now more frequently referred to as Innovation. For example, there is currently a lot of research going on related to the environment, e.g. research into advanced biofuels. Refineries are designed to mainly produce transportation fuels i.e. gasoline, diesel and jet fuel, and petrochemical feedstocks. This is not likely to change significantly over the next few years. However, oils produced by algae, which can be processed in refineries to produce diesel, seem promising, as they consume CO_2, don't need arable land or fresh water, and are non-edible crops. This sounds like a utopian solution, but it needs to be scaled up from pilot plant stage to industrial level, and this means more scientific research, which is another driver of change, and partnerships with universities.

Digital transformation will also help companies to achieve their economic and environmental targets. This will be developed further later on.

To achieve their net zero targets, refining companies will also **diversify or re-orientate** their activities towards renewable electricity, or towards gas rather than oil production. This will reduce their scope 3 emissions. According to Patrick Pouyanne, CEO of Total, the electricity market is going to grow rather than the oil market.[6] Some supermajors like Shell are selling their refineries. This could also help to keep the support of investors.

Offsetting, investing in decarbonisation projects, is also a way for energy companies to reduce their scope 3 emissions and reach their climate targets.

4. *Marine Insurance - IMO 2020: the perfect storm*, SCOR Technical Newsletter, May 2019 – https://urlz.fr/g6Vt
5. *Petroleum refining and insurance,* SCOR Technical Newsletter, November 2016 – https://urlz.fr/g6Vy
6. *There is question on the longevity of petroleum companies,* Patrick Pouyanne, Le Monde, 4 June 2020

WHY DOES THIS MATTER?

Every day of the year, 700[7] or so refineries throughout the world process around 82 million barrels of crude oil to produce gasoline for our cars, diesel for our cars and trucks, kerosene for commercial planes, fuel oil for ships, etc. In addition, refineries provide feedstocks for petrochemical plants to produce plastics, fibres, and other chemical intermediates. Asphalt for our roads also comes from refineries. They are an essential part of the economy. **The demand for oil products is set to grow for at least 10 years** (see Figure 2), and refining capacity is expanding in Asia (especially in China and India) and in the Middle East.

According to the IEA (International Energy Agency)[8], *"In the absence of a larger shift in policies, it is still too early to foresee a rapid decline in oil demand. Upward pressure on oil demand increasingly depends on its rising use as a feedstock in the petrochemical sector. Despite an anticipated rise in recycling rates, there is still plenty of scope for demand for plastics to rise, especially in developing economies."*

Chemical products derived from oil and gas are ubiquitous in our day-to-day lives. Wherever we are, we are surrounded by plastics, rubber or synthetic textiles – for our convenience. The world depends on chemicals.

DEMAND FOR PETROLEUM PRODUCTS IS STILL INCREASING

The total number of cars around the world amounts to approximately 1 billion. This number could double by around 2040, mostly driven by China and India, which is easy to understand when looking at the current number of cars per capita in these countries compared to "Western" countries (Motor vehicles in use per 1,000 inhabitants: US 910, Japan 591, France 479, United Kingdom 469, China 231, India 50). The growth potential of access to mobility in China and India is gigantic. The same could be said for access to power. In addition, the number of trucks is forecast to double, to around 800 million by 2040. According to the most optimistic forecasts,[9] Electric Vehicles (EVs) could represent 58% of new sales, with up to 500 million by 2040 (from 2 million in 2018), which means the number of Internal Combustion Engines (ICE) cars would still increase until 2040. Electric motors will not replace engines for trucks, ships and planes any time soon. It is estimated that 7 million barrels per day of petroleum products will be displaced by EVs and e-buses by 2040, mainly gasoline. However, pre-Covid it was forecast that the number of people flying each year would almost double by 2040, requiring an additional 40,000 planes. This number might be revised downwards, but it will still be significant. The impact of electric vehicles on oil demand will be modest in the next decade. This is why the demand for petroleum products is forecast to grow at least until 2030 and then decrease slowly.

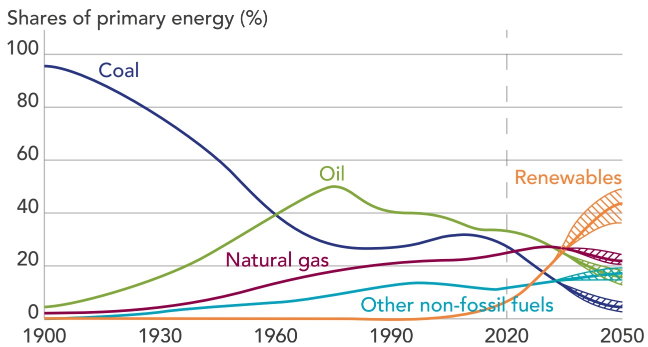


FIGURE 2: EVOLUTION OF ENERGY MIX

Source: SCOR

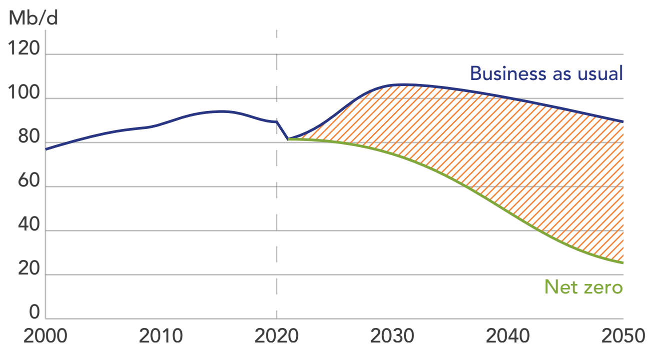


FIGURE 3: OIL CONSUMPTION

Source: SCOR

7. *Petroleum refining and insurance,* SCOR Technical Newsletter, November 2016 – https://urlz.fr/g6Vy
8. *World Energy Outlook,* IEA, 2020 – https://www.iea.org/reports/world-energy-outlook-2020
9. Long-Term Electric Vehicle Outlook 2020, BloombergNEF – https://about.bnef.com/electric-vehicle-outlook-table-of-contents/

THE REFINERY OF THE FUTURE WILL HAVE A LOWER CARBON FOOTPRINT

To address scope 1, 2 and 3 emissions, refiners are working on a wide range of solutions, using a combination of new products and new or improved processes. CO_2 production needs to be reduced. This means that the energy intensity of processes needs to be reduced, which in turn means that **innovation is required**[10].

TACKLING SCOPE 1 & 2 EMISSIONS

Low carbon intensity feedstocks to produce advanced biofuels

Liquid biofuels, requiring minimal changes to fuel distribution infrastructure or the transport fleet, can be deployed rapidly to cut greenhouse gas (GHG) emissions. Ethanol and biodiesel are known to reduce our carbon footprint and we have observed many refiners investing in new production facilities or converting existing refineries.

Advanced biofuels are commonly accepted to be biofuels that are produced from lignocellulosic feedstocks (i.e. agricultural and forestry residues), non-food crops (i.e. grasses, miscanthus, algae), or industrial waste and residue streams (animal fats, cooking oil, municipal waste). They produce at least 60% less GHGs than fossil fuels. World sustainable biomass availability is generally expected to increase continuously from a total of 2,500 Mtoe/y by 2020 (IRENA reference) to 5,700–7,000 Mtoe/y by 2050 in the max scenario (IEA/IRENA reference) mainly based on agricultural residues and energy plants (>70%). A lot of research is going on to improve feedstock supply (breeding efforts, genetics) and the biomass to biofuel process chain, to decrease conversion costs, to convert algae to biofuel, and so on.

There are several conversion and upgrading process technologies (pyrolysis, hydrolysis, hydrothermal upgrading, gasification) at different stages of development, from research and prototype to commercialisation. However, to be competitive, advanced biofuels need an oil price of around USD 100/bbl.

Lower carbon intensity crudes

When looking at the overall carbon footprint, the carbon intensity of feedstocks must be taken into account. In the future, green hydrogen and renewable electricity will lower the carbon intensity of refineries. But more immediately, refineries can select crudes based on their carbon intensity.

CCS, a key component to achieve carbon neutrality

CCS involves capturing CO_2 from flue gases, purifying and compressing it, and then either storing it by injection in geological formations or using it for enhanced oil recovery, food and beverage manufacturing, or chemical intermediates. There are several technologies in use or under development, which use chemical absorbents (amines) or membranes, depending on the concentration of CO_2 in the gas stream.

CCS will help to reduce CO_2 emissions from the industrial sector. These represent 20% of total GHG emissions, of which refining is responsible for 0.7 Gigatonnes (Gt)[11] or approximately 10% of the industrial sector. CO_2 emissions from refineries originate from four main sources: process heaters (30-60%), Fluid Catalytic Cracking (20-50%), hydrogen production (5-20%) and utilities (20-50%).

According to BP[12], CCS could reduce CO_2 emissions by 5.5 Gt by 2050 in the net zero scenario, vs. current CO_2 emissions of 34 Gt.

In the commercial "first generation" technology used in around 100 projects around the world, the cost of capturing CO_2 is USD 50-75/tonne, with 95% CO_2 purity. The third generation technology is currently in the research and development phase, and will produce 99% purity CO_2 at USD 30/tonne from around 2040.

There are already several examples of refineries with CCS either in operation or planned for the near future. Shell Canada's upgrader CCS has been operating since 2015, capturing 1 million tonnes per year. The more recent North West Redwater refinery in Canada has a CCS system capturing 1.2 million tonnes of CO_2 per year, and CCS is also being tested in Preem's Lysekil refinery. There are also several blue hydrogen projects underway (combining reforming units with CCS).

10. *Petroleum refining and insurance,* SCOR Technical Newsletter, November 2016 – https://urlz.fr/g6Vy
11. *Technology Scouting – Carbon Capture*, Concawe, September 2020 – https://www.concawe.eu/publication/technology-scouting-carbon-capture-from-todays-to-novel-technologies/
12. BP Energy Outlook 2020 – https://www.bp.com/en/global/corporate/energy-economics/energy-outlook.html

Use low-carbon energy sources

Refineries consume a lot of energy in the various processes involved in heating or process furnaces, where either fuel oil or gas is burned to raise the temperature of products to as high as 400-500°C. In the future, gas or fuel oil fired heaters could be converted to electrical or hydrogen furnaces. Power is also necessary for rotating machinery such as compressors. In the future, this power could come from carbon-neutral sources.

Reduce, re-use, re-cycle

Another contributor to the sustainability of refineries is recycling: plastics waste can be converted to plastics or oil. OMV's ReOil pilot plant at the Schwechat Refinery in Austria recycles post-consumer recycled plastics and turns those plastics into synthetic crude, which in turn can be processed into any desired refinery product. Substituting crude oil with post-consumer plastics synthetic crude is estimated to lead to 45% lower CO_2 emissions linked to the use of crude oil, and 20% lower energy demand per tonne of product. Since it began operating in 2018, OMV's ReOil pilot plant has managed to successfully recycle 200,000 kilograms of plastic waste, with a processing capacity of up to 100 kg/h and a production capacity of up to 100 litres/h of synthetic crude, which is then further processed in the refinery. OMV plans to do one more scale-up step of the plant by 2022 by increasing the post-consumer plastic feedstock capacity to 16,000 - 20,000 tonnes/year, before aiming at building the final industrial-scale capacity plant by 2025.

Plastics directly from oil and economies of scale

To make refineries more efficient, processes are being adapted to produce plastics. New refineries are reaching higher margins, and they tend to be large and integrated with petrochemical units. While the long-term demand for petroleum products is predicted to decline at some point in the not too distant future, the consumption of petrochemical products and plastics is likely to continue rising for decades. Recent projects include RAPID (Refinery And Petrochemical Integrated Development) in Malaysia, which started up in 2020. The largest project currently underway is the Aramco-ADNOC mega refinery and petrochemical complex in India, with a capacity of 1.2 million barrels per day and a cost estimate of USD 60 billion.

Improve energy efficiency, obviously

Improving process efficiency is part of refineries' strategy to reduce CO_2 emissions. Research and development centres are actively and constantly looking to improve processes in order to be less energy intensive and to operate at lower pressures or temperatures, for example by improving catalysts.

The role of artificial intelligence in this will be developed in the next section.

Importing green hydrogen will lower refineries' carbon intensity

Currently refineries, along with ammonia and methanol plants, are the main producers of hydrogen – by steam methane reforming and as a by-product in catalytic reforming units. Refineries, fertilisers and methanol plants are also the main consumers of hydrogen as a raw material in chemical processes. In refineries, hydrogen is a raw material in hydrodesulphurisation units and hydrocracking units.

Importing green hydrogen, instead of producing grey hydrogen by steam reforming, will improve GHG reduction targets. Refining is expected to switch to low-carbon hydrogen over the next decade[13].

As an example, between the Lingen and Gelsenkirchen refineries in Germany, BP, Evonik, Nowega, OGE, and RWE Generation are currently developing the first publicly accessible hydrogen infrastructure over a 130 km-long network as part of the GET H2 Nucleus project, to be completed in 2022[14]. Green hydrogen, as a raw material, will be delivered to BP refineries and the Marl chemical complex. Hydrogen will also be used for mobility, heat, and power generation. Existing natural gas pipelines can be converted to transport hydrogen. This could be a model for the future gradual integration of green hydrogen and refining.

OMV Schwechat refinery just announced the construction of a 1,500 tonnes/year green hydrogen plant, to start up in 2023, as part of their target to reach net zero emissions (scope 1 and 2) by 2050.

13. *Hydrogen Insights Report 2021*, Hydrogen Council, McKinsey & Company – https://hydrogencouncil.com/en/hydrogen-insights-2021/
14. *Hydrogen infrastructure – the pillar of energy transition*, Siemens Energy, 2020 – https://www.siemens-energy.com/global/en/offerings/industrial-applications.html?gclid=EAIaIQobChMIuvio897L8QIV1IBQBh2HvwY-EAAYASAAEgIT7_D_BwE

TACKLING SCOPE 3 EMISSIONS

E-fuels as an alternative

E-fuels or electro-fuels (also called power to liquid) are emerging synthetic fuels produced by reacting green or blue hydrogen (produced from renewable sources) with CO_2 to produce hydrocarbons, via Fischer-Tropsch (FT) synthesis and subsequent hydrocracking. Their advantage is that they could be used in cars like petrol, without modification, and distributed with current infrastructure. They are carbon neutral, as they produce as much CO_2 by combustion as they take from the atmosphere.

Produce green hydrogen as an alternative fuel

Burning hydrogen to produce energy produces no CO_2. Hydrogen has the potential to move cars (which has already been proved) and in the future buses, ships and perhaps planes. It's perfectly clean and doesn't produce any pollution. It could potentially replace all types of transportation fuels.

To produce hydrogen today, however, the most common method (generating "grey" hydrogen) is Steam Methane Reforming (SMR), which produces CO_2. Hydrogen production through steam reforming is expensive, so considerable research is going into reducing costs and minimising CO_2 production. The most promising solution is to produce "green hydrogen" in electrolysers using renewable power.

This is a perfect combination as, in addition to being carbon neutral, hydrogen is also a way to store energy and even out the fluctuations of wind and sun. That's why, according to Wood McKenzie, it could meet 7% of global final energy demand by 2050[15] (18% according to the hydrogen council[16]). Total investments in hydrogen projects could exceed USD 300 billion through 2030.

Hydrogen is indeed a new type of fuel for the transportation sector, the main customer of refineries. In the future, refineries may well produce green hydrogen, to be used for their own refining processes and also as an alternative transportation fuel to compensate for the reduction in hydrocarbon fuels.

By 2050, green hydrogen will replace grey hydrogen, and 30% of the demand for hydrogen could come from transportation (ground, marine, and aviation) and heating. Many green hydrogen projects are already planned.

THE REFINERY OF THE FUTURE WILL BE FULLY DIGITAL

Digital transformation has become a hot topic for refiners, due to its potential significant impact on operations and margins. The coronavirus pandemic has only accelerated the timeframe for action. These technologies provide the means to transform Operational Frameworks wholly and fundamentally. Refining is a good candidate for digital transformation, because of the enormous amount of data it generates and the complexity of the operations requiring optimisation. At the present time, many systems in refineries don't communicate automatically - e.g. operations and planning. Optimisation can be improved, translating into margin gains as well as safety and environmental benefits. In June 2018, two announcements were made on the future of refineries that brought something new - not just a development, but something transformative. First, Repsol announced that it was partnering with Google, in order to optimise production and maximise margins at the Tarragona refinery in Spain, and then if successful, extend to other refineries. A few days later, Total announced the creation of an innovation centre with TATA Consulting, specifically to improve the performance of the Donges refinery in France - i.e. very similar to the Repsol project. Both companies then launched major digital transformation programmes for their groups.

Few people were aware, until then, that there was a possible bridge between "tech" companies like Google and industrial companies. But it makes sense. This fourth industrial revolution began recently and will no doubt develop over the next few years, with some leaders and some followers, but it's happening and it's the future.

15. *Hydrogen's critical role in the energy transition,* Wood Mackenzie, 5 February 2021 – https://www.woodmac.com/news/the-edge/hydrogens-critical-role-in-the-energy-transition/
16. *Hydrogen Scaling up*, Hydrogen Council – https://hydrogencouncil.com/wp-content/uploads/2017/11/Hydrogen-scaling-up-Hydrogen-Council.pdf

SCOR contacted several risk managers, including at TOTAL and Repsol, to get a better understanding of the progress and scale of the implementation of digitalisation.

These interviews convinced us that digital transformation is a very important innovation area for refiners. The general findings were relatively consistent, from what the risk managers were able to share.

1. All agreed on the main **drivers** for change, starting with the need to improve margins and the pressure from competition. This translates into improving performance, reliability and efficiency. Safety was mentioned several times, not surprisingly because of the presence of dangerous processes leading occasionally to fatalities. Finally, refineries are prime targets for environmental legislation, which is another reason to advance with digital projects.

2. **Digital Transformation** (DT) can no longer be ignored and has become a priority for many refineries, even though they have developed better process controls. It is obvious that some are trailing behind and will need to catch up.

- Digital Officers, reporting to CEOs, have implemented units made up of existing functions, such as IT, and new specialists. Collaborative work and openness are essential, and breaking silos is key. This signals a new thought process, working within existing networks. It is important for experts from different professional cultures to work together, for example IT teams have more of a security culture, whereas OT (operational technology, usually Industrial Control systems) experts come from a safety culture.
- Refiners are responding in different ways to the digital challenge, but most are using "Big Data" partners, e.g. Google, Microsoft, SAP, and so on. Working with startups is common, and some companies even have a startup incubator. This new approach to development focuses on collaboration and collective input.
- Working with peers is commonplace and welcome, especially on digital innovation related to safety and reliability issues. Examples are the American Petroleum Institute (API) and the Canadian Association of Petroleum Producers (CAPP).

3. There are **challenges,** however, starting with the management of these huge and complex projects whose results are uncertain. Making the right technological choices is crucial. Digital transformation comes at a high cost, and therefore brings financial constraints. However, technology alone will not be enough, people need to be involved. With

A new **vocabulary** has emerged in the last few years, with buzz words like advanced analytics, **IIOT** (Industrial Internet of Things, the integration of data with physical processes) Big Data, Artificial Intelligence (**AI**), machine learning, **smart** devices, Digital Transformation, **connected** plants, **Industry 4.0, agility, and augmented** workers. These new terms are a sign of major change, novelty and innovation.

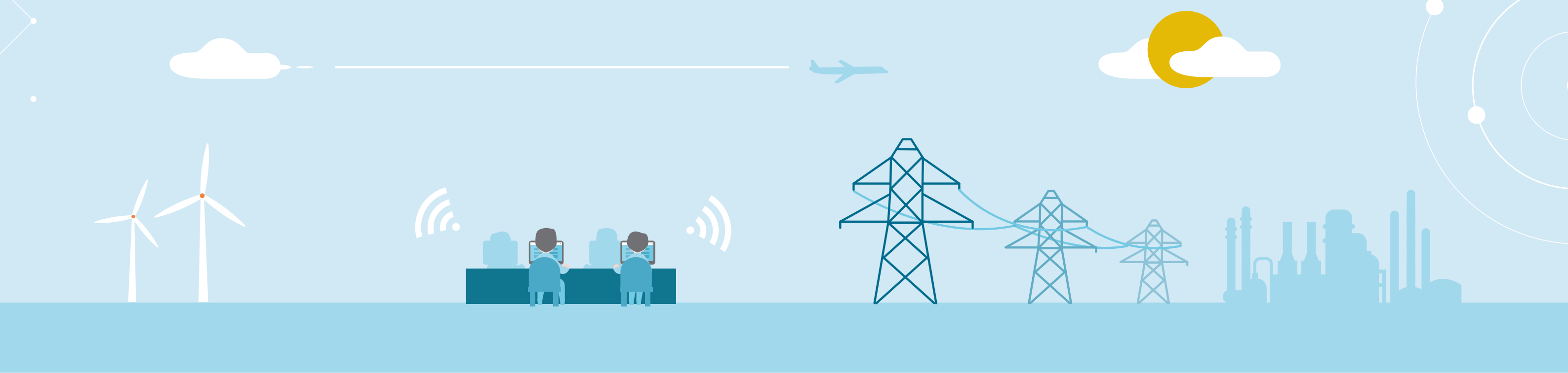
Although some of these words and concepts were already very familiar to consumers, such as smart phones, autonomous vehicles, apps to control appliances and devices (e.g. fridge, alarms, video monitoring, etc.), they are relatively new in the refining industry.

This new technology will enhance the sophisticated and mature infrastructure already in place, which includes advanced process controls, sensors to provide data (temperature, pressure, levels, flowrates, gas detectors, etc.), powerful computers and wireless connectivity.

Digital Transformation or Industry 4.0 is the integration of:

- new and innovative sensors, which are becoming more sophisticated, non-intrusive, and cheaper to install, and therefore can be installed at many points and provide more data (big data);
- IIOT (Industrial Internet of Things) to collect large amounts of data in the plant wirelessly, from sensors;
- advanced analytics or algorithms, i.e. mathematics to transform data into information, to optimise the refinery (AI) and provide KPIs in real time to make quick and intelligent decisions;
- cloud computing, facilitating complex and fast computing with computer power that has increased tremendously in recent years;
- smart devices and tablets, facilitating mobility;
- augmented operators.

FIGURE 4: FULLY DIGITALISED REFINERY OF THE FUTURE



a workforce whose experience can average 20-25 years, this will involve change management (a concept refineries know well) to address the skills and culture gap. There's also a skills gap in cyber security, although there is increasing convergence between OT teams (who are more aware of when to implement patches, usually during turnarounds) and IT teams.

SENSORS ARE BEING DEVELOPED AND IMPROVED, WITH APPLICATIONS IN REFINERIES

Most of us will know the Shazam app, a powerful music recognition tool that has been in existence for a number of years. Shazam makes sense of noise and small signals, and provides a great example of artificial intelligence. The same concept can be used in a refinery, to analyse the acoustic emissions of plant equipment. It can be used for leak detection, corrosion and other abnormal conditions. It's brilliant. Experienced operators in a refinery can tell you when something is wrong or "doesn't sound right" just by listening to the equipment, but how do you model this? Neuroscientists are working on it, and again research is key. This is what artificial intelligence is all about – mathematics and algorithms – **and it's going to be a game changer for refiners.**

- Yokogawa is developing optical fibre sensors that can measure temperature, strain and vibration using Brillouin Optical Correlation Domain Reflectometry (BOCDR). This allows continuous measurement over the entire length of the optical fibre and is very useful for pipelines for example.
- Vibration and movement sensors have already been developed but are being improved.
- Nanotechnology can enable sensors to detect very small amounts of chemical vapors[17].

Two applications are of particular interest to energy insurers.

Corrosion monitoring and mechanical integrity can be improved with IIOT and AI

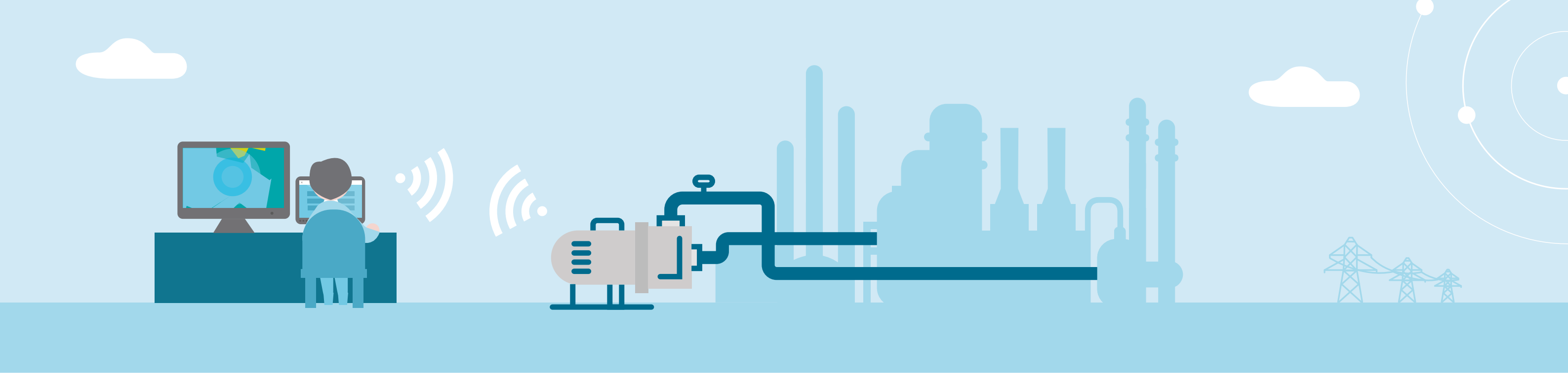
Corrosion is a major issue for refiners and insurers[18]. The flexibility to process a large number of crudes, especially high-TAN[19] crudes (with higher corrosion issues) is a competitive advantage, because they are cheaper and therefore improve refinery margins. However, as insurers well know, corrosion is one of the main causes of large losses, so monitoring corrosion, especially naphthenic corrosion, is essential. The better the monitoring, the better the performance of the plant.

Predicting corrosion is complex as it depends on many factors, such as metallurgy, crude composition (sulfur, naphthenic acids, organic chlorides, etc.), temperature, velocity, the presence of hydrogen, and so on. It's the inspection team's job to define the strategy after assessing the corrosion mechanisms. This is generally done manually, by performing thousands of tube wall thickness measurements around the refinery, at regular intervals, to calculate corrosion rates. Ideally, ultrasonic thickness measurements are taken continuously at many fixed points, allowing real-time monitoring when wirelessly connected, state-of-the-art sensors are combined with analytics. Permasense™ is an example of a non-intrusive corrosion probe using ultrasound; other sensors use an electric probe to measure electric resistance.

Maintenance will be much more predictive

Refineries contain thousands of pumps and compressors that are checked for vibration (typically manually), as well as a small number of critical, usually large ones equipped with online vibration monitoring systems. In an ideal world, many more rotating machines would be monitored with vibration analysers as well as with pressure, temperature and other sensors. This will become more economical when sensors become cheaper. Connectivity will allow this data to be sent wirelessly to a central computer, where advanced analytics can anticipate any failures in time to prevent unscheduled shutdowns. This will maximise mechanical availability, and ultimately energy intensity.

17. Various types of detecting elements, such as carbon nanotubes, zinc oxide nanowires or palladium nanoparticles, can be used in nanotechnology-based sensors. These detecting elements change their electrical characteristics, such as resistance, when they absorb a gas molecule. Because of the small size of nanotubes, nanowires, or nanoparticles, a few gas molecules are sufficient to change the electrical properties of the sensing elements. This allows the detection of a very low concentration of chemical vapors. The goal is to have small, inexpensive sensors that can detect chemicals.
They could provide a precious tool for refinery operators; they could detect the release of chemical vapors and warn of a specific leak. A new generation of nanosensors based on mesoporous silica nanocapsules, with the ability to monitor the onset of metallic corrosion has been successfully developed and tested on 304 stainless steel. The core of the nanocapsules contains water insoluble organic molecules that fluoresce during the anodic dissolution of metallic substrates in the corrosion process. This promising concept therefore offers new perspectives for the development of smart coatings for corrosion sensing.
18. Analysis of common causes of major losses in the onshore oil, gas and petrochemical industries, LMA, September 2016 – https://www.lmalloyds.com/LMA/Underwriting/Non-Marine/Onshore_Energy/Onshore_Energy_Wordings/Common_Causes_of_Losses_in_the_Oil%20_Petro_Industry.aspx
19. Total Acid Number (TAN) of a crude oil is a measure of acidity due to the presence of acids, particularly naphthenic acids



Improvement is possible through technology, as shown in the previous examples. However, the quality of monitoring will also depend on the number and quality of sensors, and consequently on the amount the refiner is willing to invest in these new systems. The predictability and therefore the prevention of failures will be greatly improved by having:

- a wider variety of data that AI will be able to cross-analyse with new algorithms;
- data being fed almost continuously, with super computers being able to analyse this big data;
- data coming from points that are closer together will be made possible because analysers will be cheaper and smaller.

The refinery of the future will also change with some progressive and continuous changes to its infrastructure: more powerful computers (the continuous improvement of computing power with the advent of super-computers and cloud computing will lead to more data being processed faster), better connectivity, and cheaper sensors.

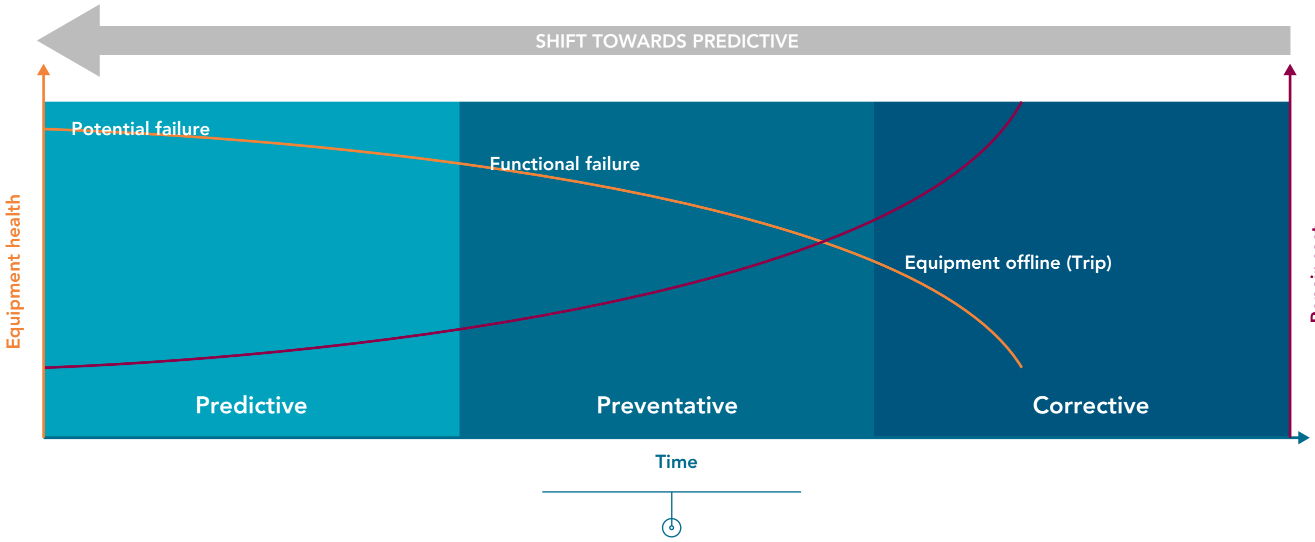


FIGURE 4: AI ENABLES THE SHIFT TOWARDS PREDICTIVE
Source: SCOR

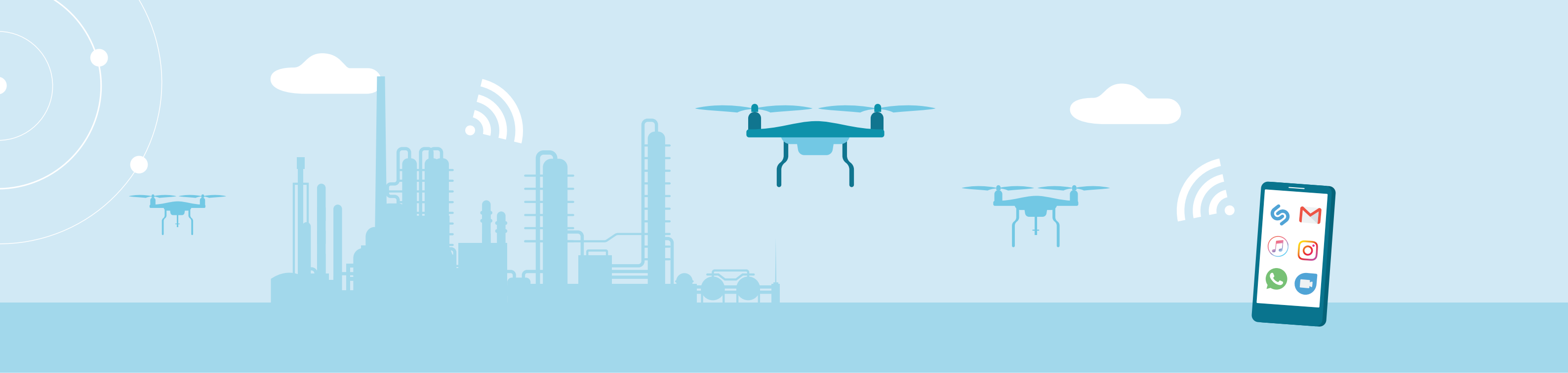
THE RISK IS CHANGING AND POTENTIALLY IMPROVING

Subject to their digital projects being completed successfully, and with the right technological choices, the risk for refiners could potentially improve. Reliability will increase. Inspection will be enhanced. Maintenance will become more predictive. Better predictability means fewer forced outages, greater mechanical availability, and therefore better margins and more efficiency. Safety should improve along with efficiency and carbon intensity.

For Risk Managers this potentially means fewer losses, less human error, and less machinery breakdown. All good news!

THE CREATION OF DIGITAL MODELS CONTRIBUTES TO SAFETY

AI enables the creation of digital doubles or digital twins of individual critical equipment, typically rotating machinery like compressors and pumps. These can be created at unit level or for the whole plant, allowing refiners to perform simulations in various scenarios before implementing any changes, and to prepare for turnarounds. The virtual model can also be used for better training, as it accurately reproduces the plant. Operator training further contributes to increased safety.



CYBER RISK WILL INCREASE

In May 2020, Taiwan's two largest oil refineries, CPC and FPCC, were both targeted by cyber attackers. According to the press, the ensuing disruption trickled right down the supply chain to impact customers at gas stations. These are by no means isolated cases – energy companies have been targeted by hackers for years. In this segment, the cyber threat is not new and is evolving with the next generation of refineries (connected plants, exponential increase of data volumes, etc.). Since the initial statistics published by the US ICS-CERT in 2010, showing a list of 41 cyber incidents impacting Energy & Utilities, cyber incidents have continued to hit this sector and include some iconic attacks, such as Stuxnet (Iranian nuclear sites – 2011), Shamoon (Saudi Aramco and RasGas – 2012), the Ukrainian power grid attack in December 2015 and the Colonial Pipeline attack in 2021.

The Triton cyber-attack highlighted a new challenge for risk managers. In 2017, attackers penetrated the safety systems of a petrochemical plant in Saudi Arabia. Their goal was to delete the sensors' alert thresholds, which would eventually lead to a fire or an explosion. Luckily, their attack was detected before creating any damage. This near miss highlighted a new challenge for risk managers: finding the right balance between the benefits of connected sensors and the increased exposure to cyber threats due to the interconnections of systems.

Cyber regulatory risk is also increasing. Worldwide, Energy companies are considered as critical infrastructures. As such, they must comply with specific cybersecurity regulations. Failure to comply may lead to significant fines from the regulator. In February 2019, the US North American Electric Reliability Corporation (NERC) recommended imposing a USD 10 million fine on Duke Energy for repeated violations of Critical Infrastructure Protection (CIP) reliability standards over more than three years.

Finally, recent cyber-attacks leveraging Microsoft Exchange Server and SolarWinds systems demonstrated the critical role of (IT) suppliers. In the energy ecosystem, hackers could target manufacturers of connected machines and use them as access points to Energy companies' IT systems at scale.

The refinery of the future includes advanced analytics, artificial intelligence, edge computing, and Industrial Internet of Things (IIoT). All these technologies represent new cyber-attack vectors, but most importantly, they should be new opportunities for companies to boost their cybersecurity posture and resilience to IT attacks and failures.

Sébastien Héon
Deputy CUO, Cyber Solutions

However, to counterbalance this, more connectivity (and use of clouds) means higher cyber risk: "systems can't be 100% safe". OT systems operate for 5 to 10 years without changes, so the risk increases. Patches can't be easily applied online; the plant needs to shut down.

Other emerging risks could result from higher supply chain risk due to even more inter-connectedness and complexity, more dependence on systems and possible programming errors. This could result in accumulation of risks to a magnitude that was not imaginable without the advent of AI and IOT.

DRONES AND ROBOTS (COMBINED WITH AI) WILL MULTIPLY AND TRANSFORM INSPECTION

Drones can perform some tasks cheaper than humans, mainly when using them avoids the need to shut down the inspected equipment or build massive scaffolds, which is an enormous advantage. Drones can access areas that are difficult or dangerous for humans to access. They are already used by most refiners for the inspection of flares, pipelines, columns and gas leaks. Drones can be more reliable than humans. However, many lines will require humans for the removal of insulation in order to inspect pipes.

Because using drones is cheaper and quicker than using humans, the same inspection can be carried out more frequently, which provides more data points and offers better analysis and more predictability.

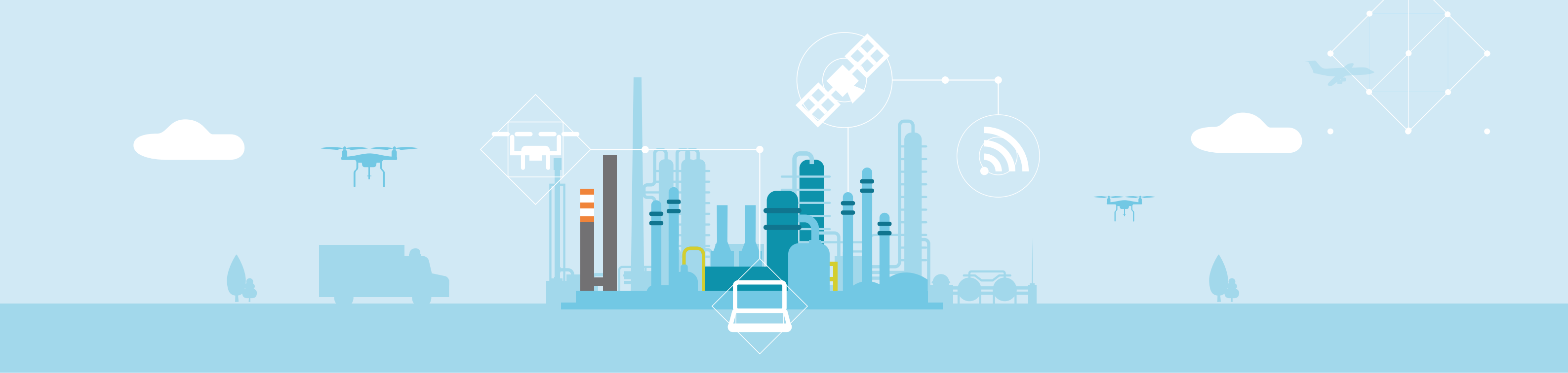
Phillips66 is partnering with Square Robot to produce a robot able to inspect tanks without emptying, i.e. in service, which is a novelty.

Collecting more data is useful for corrosion monitoring as it can vary from one point to another even a few mm away.

Information can be fed into the system in real time with immediate analysis, whereas currently it takes time to input data, sometimes manually, point by point in the system.

Drones can also assist firefighters, and as mentioned above can access dangerous areas, with small water tanks.

Drones and robots will improve with technology (e.g. high resolution cameras, thermal imaging, gas analysers) and multiply (like autonomous vehicles in our daily lives). In the future, they will be pre-programmed and autonomous,



and more "intelligent". They could for example decide themselves to increase the frequency of some inspections if an anomaly is detected. They could decide where to inspect and find inspection points without a pilot. Providing a wealth of quality data in real time as part of the IIOT system, they will improve the reliability and optimisation of the plants and make the digital transformation even more powerful.

A NEW WORLD FOR INSURERS TOO

Nat Cat specialists have been reviewing their models to anticipate the changes caused by climate change. Underwriters have to deal with the uncertainty of emerging phenomena linked to global warming. The frequency of extreme weather events is predicted to grow, e.g. hurricanes, wildfires, deepfreeze, and so on.

In a competitive energy sector with low margins, underwriters need to understand the business models of their clients and how sufficient margins can be generated to maintain the plants and invest in a way that doesn't impact the quality of the risk involved. Insurers will also need to understand how well clients are navigating through uncertain and low margin waters during the energy transition, and the implications of environmental legislation in the different jurisdictions where plants are located.

The **ESG ratings** of refining companies are a growing factor in our underwriting, as are the methods and strategies used by our clients to tackle climate change and work towards decarbonisation. Underwriters are being trained and becoming familiar with TCFD (Task Force for Climate Related Disclosure). Most insurers today have restrictions on underwriting occupancies related to coal. Transition risks are being considered. Reputational risks will also be taken into account. Insurers in turn depend on financial ratings which include ESG factors.

Canadian oil sands companies have pioneered detailed and dedicated ESG presentations, as they have been targeted by activists. Today it is the norm to address ESG and climate change in renewal discussions with clients, whereas just two years ago this was not an issue.

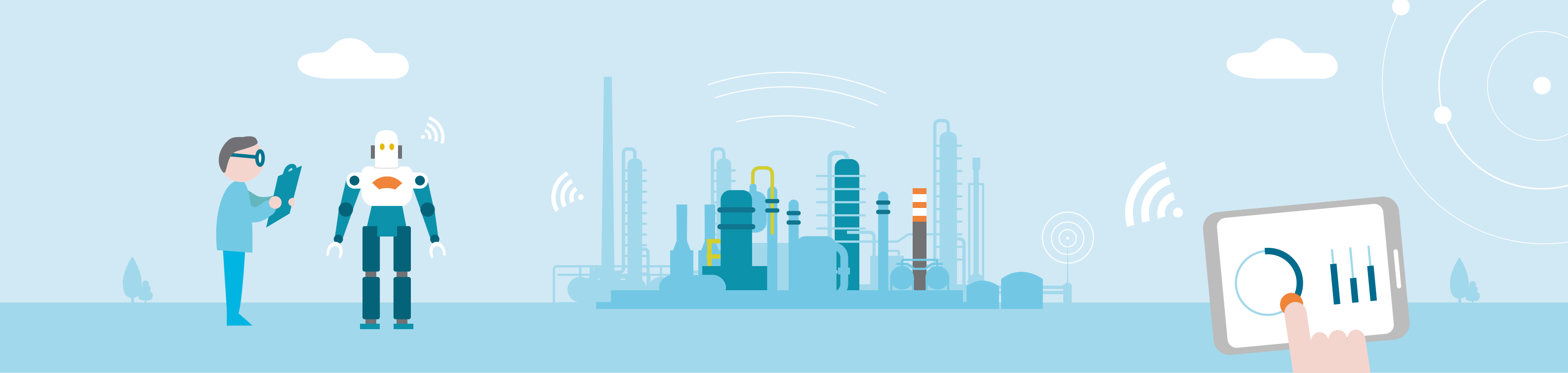
Wordings and contracts will integrate climate change risk. Carbon credits will increasingly be part of wordings, a direct consequence of climate change.

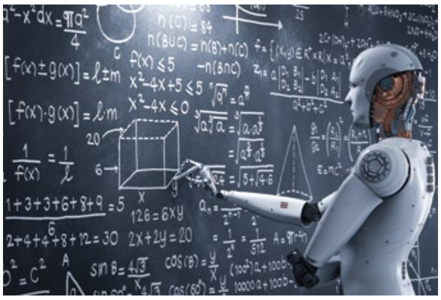
For underwriters, digital transformation will certainly mean that underwriting information will change, and new skills will be required. One could imagine, long term, "augmented underwriters" being connected to the plants, with online KPIs (maintenance, inspection, operations) and even real-time adjustment of premium based on a set of parameters including refining margins, for which a more complex model could be created.

FIGURE 5: UNDERWRITER/RISK ENGINEER AT WORK

Insurers will have to address their own skills gap challenge and they will need to keep up in a fast-changing environment. Underwriters will have new tools, using AI themselves to analyse data. Tools already exist that rate companies' vulnerability to cyber-attacks. These tools will improve to help insurers and their clients to assess risks. AI should also be able to help assess supply chain risks, and to assist underwriters and their back-office with data processing.

The risk engineers of the future could benefit from AI and IIOT enabling them to analyse the quality of the digitalisation systems and the impact on the "risk quality". New processes and products like biofuels and hydrogen are fairly well known from a hazard analysis point of view at first glance, but this must be looked at in more detail. Risk engineering teams in the future will include cyber, big data and perhaps also ESG experts.





We could imagine the use of drones to perform surveys in difficult to reach areas. Digital doubles will allow risk engineers to assess various business interruption scenarios, enabling rapid quantification of interdependencies in many scenarios compared to today's situation, where insurers mainly focus on the worst-case scenario.

Claims experts and their loss adjusters will also need the expertise to understand the root causes of losses when these are linked to digitalisation.

Loss adjusters already use drones very effectively just after a loss to record a large number of images. This speeds up the adjustment process as often access to the plant is restricted following a major loss.

Valuation companies should be able to develop more sophisticated tools in the future, with the ability to access and process higher volumes of data. This will enable risk managers and insurers to get more frequent and more accurate property values, reducing the uncertainty involved for the benefit of all parties.

It's always interesting to see how Science Fiction directors and artists help us visualise the future, and how that vision has evolved from the Daleks to Wall-e and more recently to Humans 2.0. and Blade Runner 2049. It also shows, retrospectively, how we get it wrong and how difficult it is to predict the future.

The Economist published a survey[20], having consulted experts, about the timeframe for change with regard to AI and its impact on daily life. Folding laundry automatically will be a reality in a few years' time, truck driving will be autonomous in 10 to 20 years, full automation of work possibly in 100 years. None of us will probably be around but it provides food for thought! At least in the short term we will still need humans!

ESG RATING AGENCIES' ROLE IS GROWING

It is now beyond question that the great Energy Transition has started and society's efforts to electrify and decarbonise every sector are picking up pace. As businesses, we all have a role to play in supporting the shift to a cleaner, greener and more sustainable future, and our progress is being increasingly scrutinised by a new breed of ESG ratings agencies. The so-called Non-Financial Ratings Agencies seek to identify the leaders and laggards on ESG issues in each industry by assessing performance against an array of indicators in each of the Environmental, Societal and Governance categories.

In many ways this is a good thing, recognising sector leaders and encouraging others to mobilise. However, at this particular stage in the maturity of these data service providers there are some challenges with the consistency, transparency and comparability of the methodologies used. It's not helpful when scores diverge which can happen due to variation in scope, measurement and weights used to assess each indicator and aggregate to a composite rating. Indeed, one study identified 709 separate indicators used by just six different rating companies, many of which are unique factors in a particular rating agency's ESG formula.

Refineries will be under increasing pressure to innovate and demonstrate how they can adapt and establish a lower carbon future, and this paper highlights some exciting developments.

Paul Nunn
CEO Senior Adviser

NEW POSSIBILITIES FOR RISK ENGINEERS

For example, notification of transgression of IOW (Integrity Operating Windows) and safe operating limits, notification of unplanned shutdowns and the bypassing of safety-critical instrumentation could provide risk engineers with a continuous view of certain elements of risk quality, versus one-off access to information during a two-yearly site survey.

Eric Lenoir
Energy Risk Control Practice Leader

20. *Human Obsolescence*, Tim Cross, The Economist, The World in 2018

CONCLUSION

In a world of energy transition and economic, geopolitical, technological and societal changes and uncertainties, energy companies need to make the right investment and diversification choices, to deal with the biggest existential threat they have ever encountered.

We have already seen a plethora of ways energy companies are transforming the industry through innovation, and this will accelerate in coming years.

The refineries of the future will be highly connected, smart, efficient, reliable, and integrated with chemical manufacturing. They will be equipped with CCS and produce oil, at least partially, from biomass and waste or recycled materials. Hydrogen will increasingly come from electrolysis powered by wind and solar farms rather than by steam reforming.

Some refineries will struggle to survive and the number of refineries in operation will gradually continue to reduce.

Concurrently, digitalisation will be transformative because it addresses refinery margins as well as reliability and energy efficiency, and therefore to some extent will help to mitigate climate change. All refiners will sooner or later have to invest in it, or they will stay far behind the frontrunners in the race to maintain acceptable margins and reduce operating costs.

Energy insurers will have to adapt as well, increasingly taking into account their clients' ESG ratings and recruiting renewables specialists and big data analysts to work alongside chemical engineers.

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