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SPECIAL FEATURES



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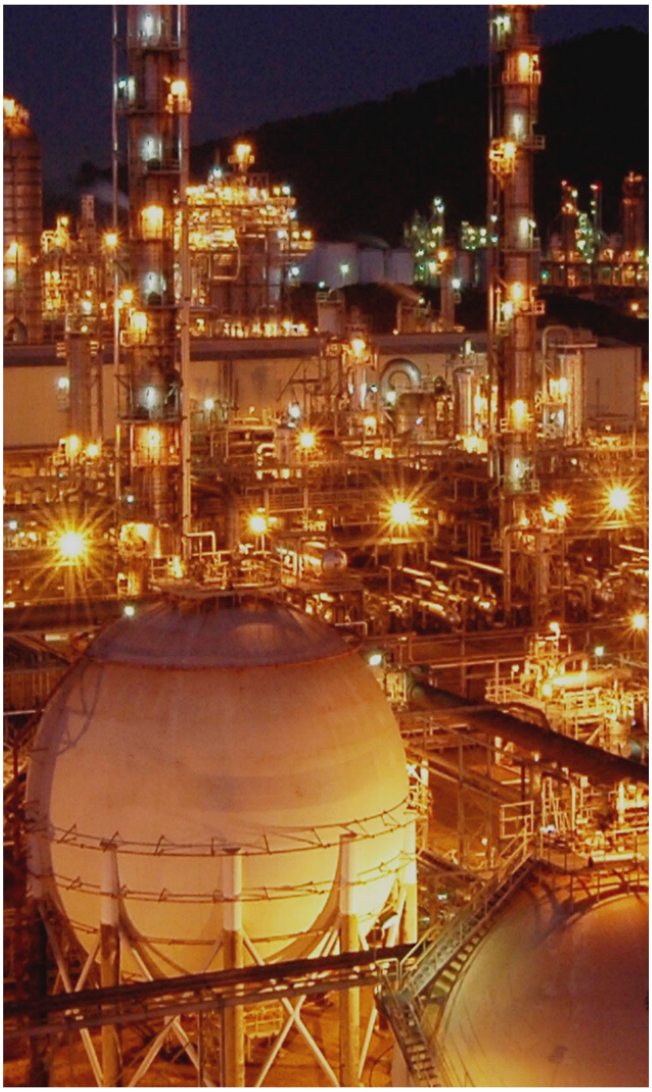

# Letter from the Editor:

# *Bone Yard*

I am currently consulting in Southern Arkansas. I often drive to Florida as I am relocating there. There is a beautiful one hour drive from Louisiana to Magnolia Arkansas. The drive has beautiful forest and low rolling hills. Around a curve there is a beautiful small church with a large cemetery.

I began to think about the people in the cemetery that used to walk on the earth. They had good times and bad times. They worked and rested. They loved and lost love. They had happiness and broken hearts. They had exceptionally good and unbelievably bad qualities.

When my son was about twelve years old we visited all my grandparent's graves with my father, his brother, and my sister. They are in Northwest Florida. I have never really wanted a large tombstone, but my father did, and he provided a burial plot for himself and my mother.

What type of legacy do you want to leave behind? A large tombstone? I know the stories my father told of his parents. The stories my mother told of her parents. I have pictures of my Great Grandparents but do not know much of them other than a few passed down stories. All they have after a few generations are tombstones in a cemetery.

Then I began to think about all the people that lived and died for generations. Most were just buried where they died. So everywhere we walk is just one large bone yard. They had good times and bad times. They worked and rested. They loved and lost love. They had happiness and broken hearts. They had exceptionally good and unbelievably bad qualities.

Sir Isaac Newton said, "If I have seen further than others, it is by standing on the shoulders of giants." Everything we have today is on this great bone yard. My grandfather Eaf Barnes was born in 1887. We live today in comforts he could not imagine by standing on the bones of others.

What do you want to leave as your legacy? A large tombstone? Most of us will never be known past three generations. The best most of us can do is to help build the boneyard for other to stand on. This involves the first half of my couplets; good times, working, loving, happiness, and good qualities.

All the best in your career and life,
Karl Kolmetz

P.S. So everywhere we walk is just one large bone yard. They had good times and bad times. They worked and rested. They loved and lost love. They had happiness and broken hearts. They had exceptionally good and unbelievably bad qualities.

# 2021 EDITORIAL CALENDER

| Month | March | May | July | September | November |
|---|---|---|---|---|---|
| Industry | Refining | LNG | Midstream & pipelines | Ethylene | Polymers |
| Unit operation | 1. Mass Transfer (Distillation)<br>2. Catalyst Systems | 1 Process control Systems<br>2. Refrigeration Systems | 1. Flaring Systems<br>2. Corrosion Control | 1. Fired heaters<br>2 Rotating Equipment | 1. Reactors Systems<br>2. Pressure Vessel Design |
| Safety, Sustainability & Digital | Biorefining | Big data | Process Safety | Water treatment – Boilers and Cooling Towers | Environmentally Friendly Circular plastic |

Rock Bottom View

# US Energy, Covid, and Beyond

Ronald J. Cormier, *Engineering Practice* Contributing Author

Very few will argue that the Covid pandemic forced a period of coping, adapting, and new behavioral patterns (in many cases, mandated by law) that resulted in altered lifestyles and ultimately, our energy consumption patterns over the last 12-15 months. To gain a feel for just how abnormal these patterns strayed from history, let's have a look at consumption data previous to this period.

Fossil fuels—petroleum, natural gas, and coal—have accounted for at least 80% of energy consumption in the United States following World War I. Overall energy consumption in the United States reached a record high in 2018 at 101 quadrillion (quads) British thermal units (Btu), of which more than 81 quad Btu were from fossil fuels. Despite the increase, the fossil fuel share of total U.S. energy consumption in 2018 increased only slightly from 2017 and was the second-lowest annual increase since 1902.

However, the increase in fossil fuel consumption in 2018 was driven only by increases in petroleum and natural gas consumption. Coal consumption, though encouraged as a major campaign and growth initiative by the Trump administration, actually fell by 4.3% in 2018, the fifth consecutive annual decline. Then in 2020 with the onset of Covid globally, total US energy consumption fell to 93 quad Btu, down 7% from 2019.

This decrease marked the largest annual fall in US energy consumption in both percentage and absolute terms dating back to 1949. Petroleum has been the largest source of energy consumption in the United States since surpassing coal in 1950. U.S. Coal consumption peaked in 2005 and has declined nearly 42% since then. U.S. coal consumption fell to 687 million short tons in 2018, the lowest level of coal consumption in the United States since the 1970s.

Natural gas consumption increased in 2018, reaching a new record consumption level of 82.1 billion cubic feet per day. Natural gas consumption had increased in 8 of the past 10 years between 2008-2018. Growth in natural gas consumption has largely been driven by increased consumption in the electric power sector. Overall, U.S. consumption of natural gas has increased by 37% since 2005.

Before 2020, the largest recorded annual decrease in US energy consumption occurred between 2008 and 2009, when consumption fell by 5% during the economic recession. Other large annual decreases in US energy consumption occurred during economic recessions in the early 1980s and in 2001. In 2020, energy consumption by the US commercial sector fell by 7%, to less than 17 quad. Retail sales of electricity to industry fell by 8%.

With people spending more time in their homes because of various mandates during 2020, sales of electricity to the US residential sector increased by 2%. However, 2020 was a relatively warm year, which led to less energy consumption for home heating. US residential consumption of biomass (mostly wood), fell by 16%, petroleum by 11%, and natural gas by 7%. Closed offices, failing businesses, travel restrictions, work-from-home orders, and relatively warmer winter weather contributed to less commercial energy consumption. US commercial natural gas consumption dropped by 11%, and electricity retail sales to the commercial sector fell by 6%.

Petroleum consumption also increased in 2018 as petroleum product supplies reached the equivalent of 20.5 million barrels per day. Despite the 2018 increase, U.S. petroleum consumption remains lower than its peak consumption level set in 2005. Overall in 2020, US consumption of jet fuel dropped by 38%, motor gasoline by 13%, and distillate fuel oil (diesel) by 7%.

The renewable share of energy consumption in 2018, which includes hydroelectricity, biomass, and other renewables such as wind and solar, was 11.4%, slightly less than its 2017 share. The largest growth in renewables over the past decade has been in solar and wind electricity generation.

Energy consumption in the United States has undergone many changes in the nation's history. From wood, dung, and whale oil as primary heating/ cooking resources in the 18th and 19th centuries (and before the advent of air conditioning), to the growth of coal and petroleum use, to that of nuclear power in the late 20th century, and now, renewables in the early 21st century. With the recent change in U.S. federal executive administration and an evenly split Senate, additional trends toward more renewable (or more importantly, production of lower emissions of greenhouse gases) should act to continue altering our energy choices going forward.

Sam Schurr and Bruce Netschert's Energy in the American Economy, 1850–1975: Its History and Prospects
U.S. Department of Agriculture's Circular No. 641, Fuel Wood Used in the United States 1630–1930, published in 1942.
EIA's Monthly Energy Review, U.S. energy consumption (estimates) from 1635-1945. Data for 1949 through the present day are available in the latest EIA MER

# Cash for Carbon | Programs to Kickstart CO2 Recovery Projects

Anne Keller

In project development, a key aspect of success is knowing who is paying the bills. As with previous efforts to reduce greenhouse gas emissions, the primary source of funding for new basic research and demonstration projects that target CO2 capture and removal from the atmosphere will be government programs. There are currently 2 key pieces of legislation which have and are expected to provide funding for these projects. The first is a tax credit, known as the "45Q" credit, which was originally created as part of the quest to reduce the environmental impact of using coal in the Energy Policy Act of 2005. The second major piece of legislation has taken 15 more years to negotiate and pass but was finally included as part of the appropriations bill that funded the 2020-2021 US Federal budget as the Energy Act of 2020. This bill was finally signed by then President Trump in December 2020. This article describes the provisions of these 2 programs and examines the track record of some of the projects that have been developed to date to highlight potential opportunities and risks for current projects.

While the mainstream media was focused on the controversy over the November elections and the pandemic, publications across the political and business spectrum praised the new energy legislation. The Washington Post described the Energy Act of 2020 as "…one of the biggest victories for U.S. climate action in a decade. Congress has moved to phase out a class of potent planet-warming chemicals and provide billions of dollars for renewable energy and efforts to suck carbon from the atmosphere as part of the $900 billion coronavirus relief package. The legislation… wraps together several bills with bipartisan backing and support from an unusual coalition of environmentalists and industry groups."

The 2005 Federal legislation was directed primarily toward allowing the US to continue using coal as an energy source for power generation by reducing the emissions footprint of both existing and new power plants. The economic motive at the time was similar to the rationale applied by the Carter administration in the late 1970's when it was assumed natural gas would be scarce and costly in the future.

Natural gas prices in the early "aughts" (2001-2008) were rising as the gas supply bubble of 1986-2000 seemed to have been exhausted by the demand for gas to replace coal in new "peak" power plants.

The key provisions of the 2005 Act that support carbon capture/recovery and sequestration projects are:

- Section 48A and 48B tax credits for "clean coal" projects. These included IGCC (Integrated Gasification Combined Cycle) power plants and "other" advanced coal-based electricity generation technologies. The law was modified to require these projects to include equipment to capture and sequester at least 65% of CO2 emissions; gasification projects were defined as those that capture and sequester at least 75%. The credits under these provisions totalled over $2.5 billion, and the program. One part of the program required projects to be placed in service by 2016, and the IRS isn't currently accepting applications for the Section 48A credits at this time.
- Section 45Q tax credits, 2005-2018. The 2005 legislation also provided a per-ton tax credit for CO2 capture and sequestration. From 2008–2018, the incentive was $20 per metric ton for CO2 sequestered in geologic storage and $10 per metric ton for CO2 used for enhanced oil recovery (EOR) or enhanced natural gas recovery (EGR). The credit was limited to 75 million tons and as of 2014 35 million tons had been claimed. Projects that were begun under these rules will continue to receive the lower credits.
- Section 45Q tax credits, 2018 expansion. The Bipartisan Budget Act of 2018 updated the 45Q tax credit. The tax credit increased to $35 per metric ton for EOR and $50 per metric ton for geologic storage by 2026. The $35 tax credit is now also available for non-EOR CO2 utilization and direct air capture projects, opening up other CO2 markets and technologies beyond the underground storage and EOR sectors.

IRS Code Section 45Q Tax Credits 2018-2026 – Summary

| | Minimum Volume Captured (metric tons CO2/yr) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Removal Technology** | **Power Plant** | **Industrial Facility** | **Direct Air Capture** | **Construction to Begin** | **Credit period begins** | **When Credit is Available** | **Credit Value in 2026[3] ($/ton)** |
| **Dedicated Storage** | 500 | 100 | 100 | by Jan 2024 | 12 years | In Service Date | 50 |
| **Enhanced Recovery[1]** | 500 | 100 | 100 | by Jan 2024 | 12 years | In Service Date | 35 |
| **Other Use [2]** | 25 | 25 | 25 | by Jan 2024 | 12 years | In Service Date | 35 |

[1]Includes enhanced recovery projects for both oil and natural gas
[2]This category includes projects that use CO2 for photosynthesis or chemosynthesis (ex. algae or bacteria), chemical conversion, or other purposes for which a "commercial" market exists.
[3]This is the level the credit rises to between 2018 and 2026, with annual escalation. For example, the credit for projects in operation in 2022 would be $39, $26, and $26/ton for each technology type.

The expanded 45Q credit program is the one that most of the new CO2 projects currently in development are relying on to support their economics. The following table summarizes the key provisions of the program.

Currently the credit goes to the owner of the carbon recovery equipment, but the credit can be directed to whoever disposes of or uses the CO2 instead. In addition, the 45Q credits can supplement and be combined with state and local clean energy incentives. These include the California Low Carbon Fuel Standard Carbon Capture and Storage program.

Another amendment to the 45Q legislation was introduced in the Senate in March 2021 to extend the timeframe for the credit out to 2030 and to make the credit directly payable. This would allow companies that don't have a tax liability to receive payments instead of requiring projects to be structured to include parties that expect to have taxable income, expanding the potential universe of participants in these projects. As of this writing the final status of this change is uncertain, but the current program is in effect.

## PROJECT LIST AND LESSONS LEARNED

These tax credit programs were initially part of a US Department of Energy (DOE) goal to drive cleaner technology use in power generation, in particular in facilities using solid fuels like petroleum coke and coal. Some of the power projects that were approved for incentives under pre 2018 legislation are described below along with their current status.

1. Christian County Generation LLC – joint venture between managing developer Tenaska and The ERORA Group to develop the Taylorville Energy Center (TEC) in Illinois to use coal from a nearby mine. This project was cancelled.
2. Summit Texas Clean Energy (Project) LLC - The TCEP facility was designed to be among the cleanest commercial, solid-fuel power facilities in the world, significantly surpassing the emissions reduction targets for 2020 established under the Energy Policy Act of 2005. Even though it was planning to use coal from the Powder River Basin in Wyoming, the facility's emissions would be far below any limits previously permitted in the state of Texas for a fossil-fuel plant. This project was cancelled.
3. Mississippi Power Company (Kemper County Energy Facility) – a Southern company project originally designed to gasify lignite coal and store the majority of its CO2 emissions. Operations using natural gas began in 2014. In 2017 start-up and operations activities involving the lignite gasification portion of the facility were suspended. The facility will continue to operate using natural gas pending the Mississippi Public Service Commission's decision on future operations. The project was initially approved for $412 million in tax credits.
4. Faustina Hydrogen Projects, LLC – this project was developed by a subsidiary of U.S. TransCarbon LLC, to gasify petroleum coke and high sulfur coal to produce anhydrous ammonia for agricultural and industrial uses. The plant was to be located next to a fertilizer manufacturing plant in St. James Parish, Louisiana. It has not been built.
5. Lake Charles Gasification LLC - the Lake Charles CCS project was intended to demonstrate the capture of CO2 from an industrial facility for use in an independent enhanced oil recovery (EOR) application. The industrial source of CO2 was designed to be a new petroleum-coke-to-chemicals (methanol and other

by-products) gasification plant developed by Lake Charles Clean Energy, LLC (a Leucadia Energy, LLC affiliate) in Lake Charles, Louisiana. This project was cancelled in 2014 and has been redeveloped as Lake Charles Methanol, LLC by Clean Energy Resources.

6. Hydrogen Energy California LLC (HECA) - the HECA Commercial Demonstration of Advanced IGCC with Full Carbon Capture (HECA CCS) project will demonstrate an advanced coal-fired generating plant that co-produces electricity and fertilizer products. This project was initially developed by BP and Rio Tinto, acquired by SCS Energy in 2011 but still not in operation.
7. Petra Nova – this project is located southwest of Houston, Texas, at an existing coal fired power plant. The developer, Texas utility company NRG, joined forces with JX Nippon, a global oil and gas company, in a 50/50 joint venture. The CO2 recovered was piped 80 miles to a mature conventional oil field. The project operated from 2017 to May 2020, when low oil prices reached negative levels during the early weeks of the COVID pandemic. Petra Nova was conceived primarily as a technology demonstration, in which technical issues associated with dramatically scaling up a carbon capture process could be identified and resolved for the benefit of future projects, as opposed to a world scale facility intended for long term operations. NRG's website quotes the engineers on the project, Mitsubishi, as saying that the construction costs of the process used for CO2 recovery could be reduced by 30% as a result of the experience. The improved solvent they have developed is may be used at a new project in Illinois, the Prairie State plant.

Although there are a number of new power projects currently in development, observations from these previous results indicate the challenges of technology involving solid fuels gasification, which a number of these projects were planning to use, and the economic obstacles faced by solid fuel facilities after the rapid expansion of shale gas production reduced gas prices from a high of $14/mmbtu in 2008 to under $2. These projects will most likely continue to seek sponsorship by regulated utilities to provide a backstop for power offtake, or will need to have commercial agreements which provide some downside protection against a drop in commodity prices for the products they make or the oil they produce.

The 2018 expansion of the 45Q credit program to include recovery of smaller volumes of CO2 and uses other than EOR or sequestration has inspired some developers to focus on more-easily captured CO2 streams from industrial facilities such as bioethanol or ammonia plants.

Occidental (NYSE:OXY) affiliate Oxy Low Carbon Ventures is a supporter of the 45Q program, preferring this method of funding technology development to the adoption of a carbon tax. The company has created a development company 1PointFive together with Rusheen Capital Management to finance and deploy Carbon Engineering's Direct Air Capture (DAC) technology. The facility would be the world's largest Direct Air Capture (DAC) Facility. Oxy has also announced the creation of a joint venture to build a pilot plant with Cemvita Factory, a bio-engineering startup to produce one metric ton a month of bio-ethylene made with CO2.

Projects which involve permanent underground storage, as opposed to recycling CO2 as part of increasing oil production (Carbon Capture and Underground Storage, or CCUS) haven't made many headlines so far. The oil industry routinely removes and re-injects significant amounts of CO2, along with nitrogen and hydrogen sulfide, in the process of producing oil and gas from reservoirs where the concentrations of these elements exceeds allowable limits in the product moved to market. Texas has a number of so called "acid gas injection wells" used to sequester CO2. But Exxon's $260 million project to sequester excess CO2 at its LaBarge facility in Wyoming has been put on hold in spite of the 45Q program. Instead, the company has announced a plan to partner with a company called Global Thermostat to deploy direct air capture. Still, the increase in the credit, together with the ability to get it back in cash, if the amendments pass, should inspire other developers to start looking underground for possible locations.

**AUTHOR**

Anne Keller is a business developer, decision coach, scenario builder, markets expert in the "Lower Carbon Hydrocarbons" sector that includes methane, natural gas liquids, and LNG, whether "renewable" or not. She has managed mid office operations and physical supply chains for moving product from the field to the plant gate, built and licensed software products, and negotiated commercial contracts around assets and commodity purchases and sales to support long term business relationships. As a teacher, she's created fundamentals training content that has been used by thousands of industry professionals seeking a better understanding of the gas and gas liquids industry and markets.


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offers an interactive 3D-view for all designs
can be used for single stage, profile and data validation calculations
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# Achieving the Blue Ocean Strategy in the Downstream Industry | Crude Oil to Chemicals as Competitive Differentiation

Dr. Marcio Wagner da Silva

## INTRODUCTION AND CONTEXT

The downstream industry faces a transition period where the focus of the players is changing from transportation fuels to petrochemicals aiming to ensure maximum added value to processed crude oils as well as to allow the growth of low carbon energies in the global energetic matrix.

The newest threat to refiners is the reduction of the consumer market, in the last years became common, news about countries that intend to reduce or ban the production of vehicles powered by fossil fuels in the middle term, mainly in the European market. Despite the recent forecasts, the transportation fuels demand is still the main revenues driver to the downstream industry, as presented in Figure 1, based on data from Wood Mackenzie Company.

According to Figure 1, the transportation fuels demand represents close to five times the demand by petrochemicals as well as a focus on transportation fuels of the current refining hardware, considering the data from 2019. Despite these data, is observed a trend of stabilization in transportation fuels demand close to 2030 followed by a growing market of petrochemicals. Still according to Wood Mackenzie data, presented in Figure 2, is expected a relevant growth in the petrochemicals participation in the global oil demand.

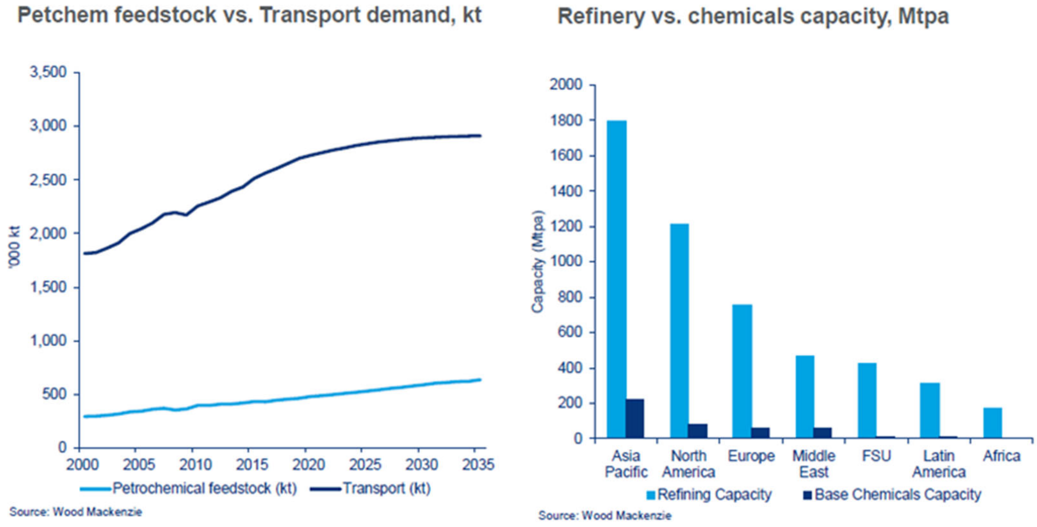


Figure 1 – Relation of Petrochemical Feedstock/Transportation Fuels Feedstock and Installed Capacity (Wood Mackenzie, 2019)

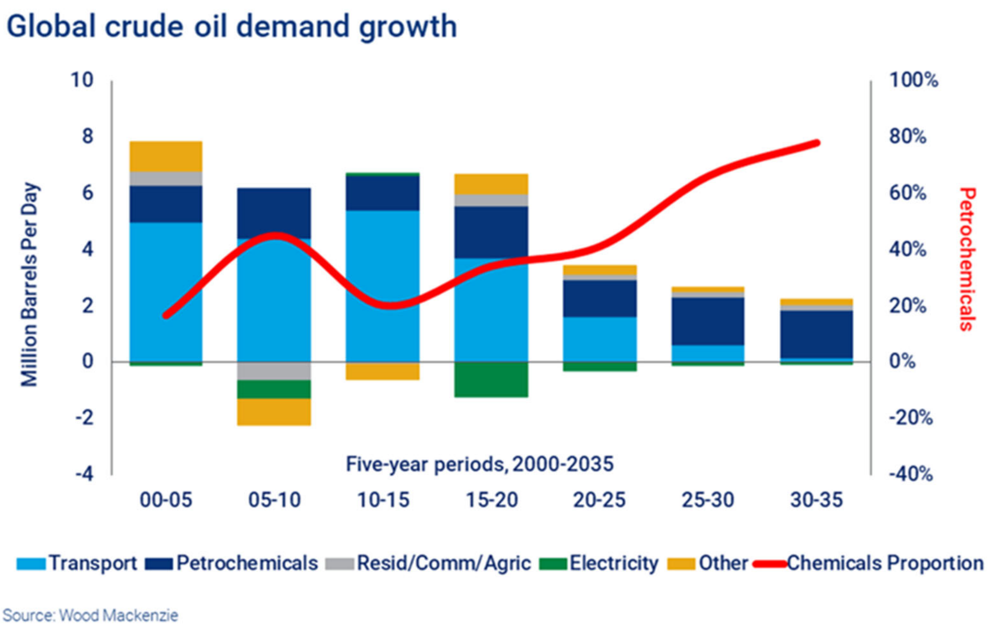


Figure 2 – Change in the Profile of Global Crude Oil Demand (Wood Mackenzie, 2020)

The improvement in fuel efficiency, growing market of electric vehicles tends to decline the participation of transportation fuels in the global crude oil demand. New technologies like additive manufacturing (3D printing) has the potential to produce great impact to the transportation demands, leading to even more impact over the transportation fuels demand. Furthermore, the higher availability of lighter crude oils favors the oversupply of lighter derivatives that facilitate the production of petrochemicals against transportation fuels as well as the higher added value of petrochemicals in comparison with fuels. According to Figure 3, the demand by petrochemicals tends to rise in the next years and can be an attract way to refiners keep his protagonism in the market.

According to data presented in Figure 3, is expected a significant growth in the market of petrochemicals intermediates, and a refining hardware capable to maximize the yield of these derivatives can offer significant competitive advantage through closer integration with petrochemical assets and higher value addition to processed crude oil. Data from World Bank and Axens Company in 2019 indicates an annual growth of petrochemicals of 4,0 % until 2025 while the transportation fuels expected to grow 1,0 % in the same period, reinforcing again the advantage of petrochemicals in short term.

Another deep change in the downstream sector that reinforces the necessity of a high conversion refining hardware is the IMO 2020. Restrictive regulations like IMO 2020 raised, even more, the pressure over refiners with low bottom barrel conversion capacity once requires higher capacity to add value to residual streams, especially related to sulfur content that was reduced from 3,5 % (in mass) to 0,5 %. Refiners with easy access to low sulfur crude oils present relative competitive advantage in this scenario, these players can rely on relatively low cost residue upgrading technologies to produce the new marine fuel oil (Bunker) as carbon rejection technologies (Solvent Deasphalting, Delayed Coking, etc.), but they are the minority in the market. The most part of the players need to look for sources of low sulfur crudes, which present higher cost putting under pressure his refining margins or look for deep bottom barrel conversion technologies to ensure more value addition to processed crude oils and avoid to loss competitiveness in the downstream market. For these refiners, deepest residue upgrading like hydrocracking technologies can offer great operational flexibility, despite the high capital spending. In this scenario, with necessity to higher value addition to bottom barrel stream and growing market of petrochemicals, refiners with adequate bottom barrel conversion capacity can achieve great competitive advantage in the downstream industry.

Based on description above it's possible to apply the article published by W. Chan Kim and Renée Mauborge called "Blue Ocean Strategy" in Harvard Business Review, to classify the competitive markets in the downstream industry. In this article the authors define the conventional market as a red ocean where the players tends to compete in the existing market focusing in defeat competitors through the exploration of existing demand, leading to low differentiation and low profitability. The blue ocean is characterized by look for space in non-explored (or few explored markets), creating and developing new

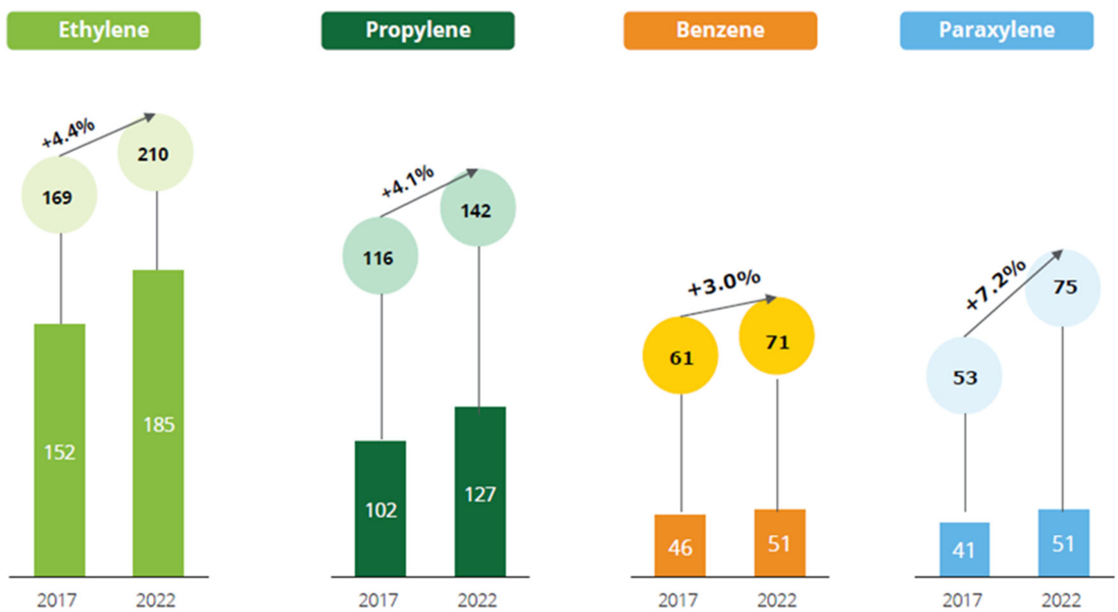


Figure 3 – Growing Trend in the Demand by Petrochemical Intermediates (Deloitte, 2019) - Note: Bars represent total demand (million metric tons or MMT), circles represent total capacity (MMT).

demands and reaching differentiation, this model can be applied (with some specificities once is a commodity market) to the downstream industry, considering the traditional transportation fuels refineries and the petrochemical sector.

Due his characteristics, the transportation fuels market can be imagined like the red ocean, where the margins tends to be low and under high competition between the players with low differentiation capacity. On the other side the petrochemicals sector can be faced like the blue ocean where few players are able to meet the market in competitive conditions, higher refining margins, and significant differentiation in relation to refiners dedicated to transportation fuels market.

As presented above, the market forecasts indicates that the refiners able to maximize petrochemicals against transportation fuels can achieve highlighted economic performance in short term, in this sense, the crude oil to chemicals technologies can offer even more competitive advantage to the refiners with capacity of capital investment.

## INTEGRATION BETWEEN REFINING AND PETROCHEMICAL ASSETS – AN INTRODUCTION

The main focus of the closer integration between refining and petrochemical industries is to promote and seize the synergies existing opportunities between the both downstream sectors to generate value to the whole crude oil production chain. Table 1 presents the main characteristics of the refining and petrochemical industry and the synergies potential.

Table 1 – Refining and Petrochemical Industry Characteristics

| Refining Industry | Petrochemical Industry |
|---|---|
| Large Feedstock Flexibility | Raw Material from Naphtha/NGL |
| High Capacities | Higher Operation Margins |
| Self Sufficient in Power/ Steam | High Electricity Consumption |
| High Hydrogen Consumption | High Availability of Hydrogen |
| Streams with low added Value (Unsaturated Gases & C2) | Streams with Low Added Value (Heavy Aromatics, Pyrolysis Gasoline, C4's) |
| Strict Regulations (Benzene in Gasoline, etc.) | Strict Specifications (Hard Separation Processes) |
| Transportation Fuels Demand in Declining at Global Level | High Demand Products |

As aforementioned, the petrochemical industry has been growing at considerably higher rates when compared with the transportation fuels market in the last years, additionally, represent a most noblest destiny and less environmental aggressive to crude oil derivatives. The technological bases of the refining and petrochemical industries are similar which lead to possibilities of synergies capable to reduce operational costs and add value to derivatives produced in the refineries.

Figure 4 presents a block diagram that shows some integration possibilities between refining processes and the petrochemical industry.

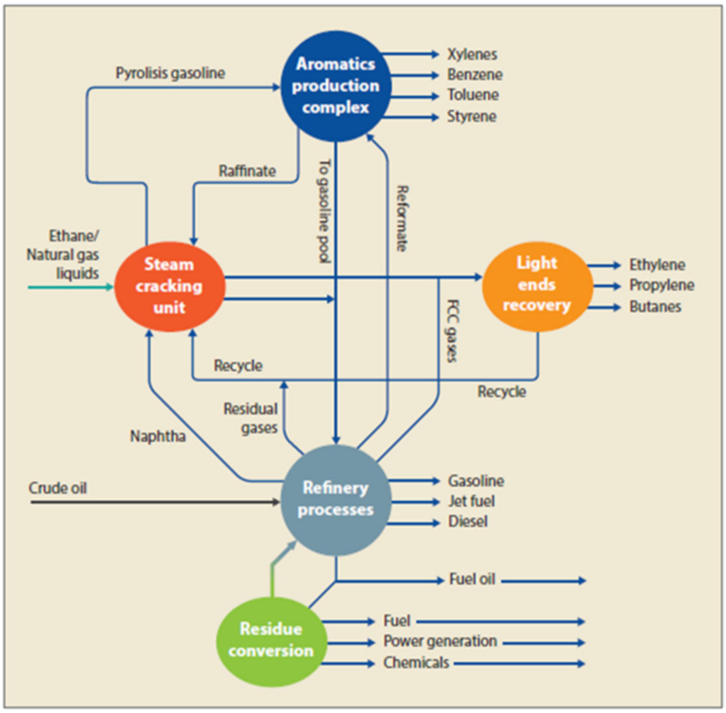


Figure 4 – Synergies Possible between Refining and Petrochemical Processes

Process streams considered with low added value to refiners like fuel gas (C2) are attractive raw materials to the petrochemical industry, as well as streams considered residual to petrochemical industries (butanes, pyrolisis gasoline, and heavy aromatics) can be applied to refiners to produce high quality transportation fuels, this can help the refining industry meet the environmental and quality regulations to derivatives.

The integration potential and the synergy among the processes rely on the refining scheme adopted by the refinery and the consumer market, process units as Fluid Catalytic Cracking (FCC) and Catalytic Reforming can be optimized to produce petrochemical intermediates to the detriment of streams that will be incorporated to fuels pool. In the case of FCC, installation of units dedicated to produce petrochemical intermediates, called petrochemical FCC, aims to reduce to the minimum the generation of streams to produce transportation fuels, however, the capital investment is high once the severity of the process requires the use of material with noblest metallurgical characteristics.

**CRUDE OIL TO CHEMICALS STRATEGY**

Due to the increasing market and higher added value as well as the trend of reduction in transportation fuels demand, some refiners and technology developers has dedicated his efforts to develop crude to chemicals refining assets. One of the big players that have been invested in this alternative is the Saudi Aramco Company, the concept is based on the direct conversion of crude oil to petrochemical intermediates as presented in Figure 5.

The process presented in Figure 6 is based on the quality of the crude oil and deep conversion technologies like High Severity or petrochemical FCC units and deep hydrocraking technologies. The processed crude oil is light with low residual carbon that is a common characteristic in the Middle East crude oils, the processing scheme involves deep catalytic conversion process aiming to reach maximum conversion to light olefins. In this refining configuration, the petrochemical FCC units have a key role to ensure high added value to the processed crude oil. An example of FCC technology developed to maximize the production of petrochemical intermediates is the RxPRO™ process by UOP Company, this process combines a petrochemical FCC and separation processes optimized to produce raw materials to the petrochemical process plants.

To petrochemical FCC units, the reaction temperature reaches 600 oC and higher catalyst circulation rate raises the gases production, which requires a scaling up of gas separation section. The higher thermal demand makes advantageous operates the catalyst regenerator in total combustion mode leading to the necessity of installation a catalyst cooler system.

The installation of petrochemical catalytic cracking units requires a deep economic study taking into account the high capital investment and higher operational costs, however, as quoted above, some forecasts indicate growth of 4,0 % per year to the market of petrochemical intermediates until 2025. In this scenario can be attractive the capital investment aiming to raise the market share in the petrochemical sector, allowing then a favorable competitive positioning to the refiner, through the maximization of petrochemical intermediates.

In refining hardware with conventional FCC units, further than the higher temperature and catalyst circulation rates, it's possible to apply the addition of catalysts additives like the zeolitic material ZSM-5 that can raise the olefins yield close to 9,0% in some cases when compared with the original catalyst. This alternative raise the operational costs, however, as

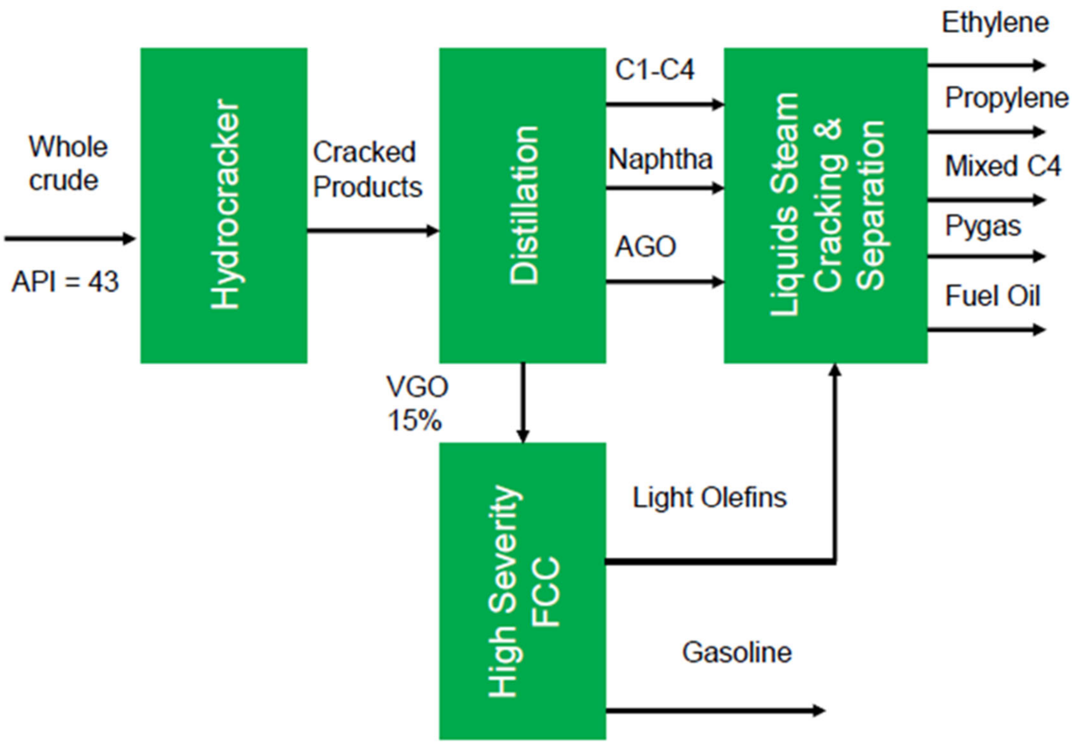


Figure 5 – Saudi Aramco Crude Oil to Chemicals Concept (IHS Markit, 2017)

aforementioned can be economically attractive considering the petrochemical market forecasts.

Installation of catalyst cooler system raises the process unit profitability through the total conversion enhancement and selectivity to noblest products as propylene and naphtha against gases and coke production. The catalyst cooler necessary when the unit is designed to operate under total combustion mode due to the higher heat release rate as presented below.

$C + ½ O_2 \rightarrow CO$ (Partial Combustion) $\Delta H = -27$ kcal/mol
$C + O_2 \rightarrow CO_2$ (Total Combustion) $\Delta H = -94$ kcal/mol

In this case, the temperature of the regeneration vessel can reach values close to 760 oC, leading to higher risks of catalyst damage which is minimized through catalyst cooler installation. The option by the total combustion mode needs to consider the refinery thermal balance, once, in this case, will not the possibility to produce steam in the CO boiler, furthermore, the higher temperatures in the regenerator requires materials with noblest metallurgy, this raises significantly the installation costs of these units which can be prohibitive to some refiners with restricted capital access.

Another key refining technology to crude oil to chemicals refineries is the hydrocraking units. Despite the high performance, the fixed bed hydrocracking technologies can be not economically effective to treat crude oils directly cue to the possibility of short operating lifecycle. Technologies that use ebullated bed reactors and continuum catalyst replacement allow higher campaign period and higher conversion rates, among these technologies the most known are the H-Oil and Hyvahl™ technologies developed by Axens Company, the LC-Fining Process by Chevron-Lummus, and the Hycon™ process by Shell Global Solutions. These reactors operate at temperatures above of 450 $^{o}$C and pressures until 250 bar.

An improvement in relation of ebullated bed technologies is the slurry phase reactors, which can achieve conversions higher than 95 %. In this case, the main available technologies are the HDH™ process (Hydrocracking-Distillation-Hydrotreatment), developed by PDVSA-Intevep, VEBA-Combicracking Process (VCC)™ commercialized by KBR Company, the EST™ process (Eni Slurry Technology) developed by Italian state oil company ENI, and the Uniflex™ technology developed by UOP Company.

In the slurry phase hydrocracking units, the catalysts in injected with the feedstock and activated in situ while the reactions are carried out in slurry phase reactors, minimizing the reactivation issue and ensuring higher conversions and operating lifecycle.

Other commercial technologies to slurry hydrocracking process are the LC-Slurry™ technology developed by Chevron Lummus Company and the Microcat-RC™ process by Exxon Mobil Company.

For this side, the Steam cracking process has a fundamental role in the petrochemical industry, nowadays the most part of light olefins light ethylene and propylene is produced through steam cracking route. The steam cracking consists of a thermal cracking process that can use gas or naphtha to produce olefins.

The naphtha to steam cracking is composed basically of straight run naphtha from crude oil distillation units, normally to meet the requirements as petrochemical naphtha the stream need to present high paraffin content (higher than 66 %). Figure 6 presents a typical steam cracking unit applying naphtha as raw material to produce olefins.

Due to his relevance, great technology developers has dedicated his efforts to improve the steam cracking technologies over the years, especially related to the steam cracking furnaces. Companies like Stone & Webster, Lummus, KBR, Linde, and Technip develop technologies to steam cracking process. One of the most known steam cracking technology is the SRT™ process (Short Residence Time), developed by Lummus Company, that applies a reduce residence time to minimize the coking process and ensure higher operational lifecycle.

The cracking reactions occurs in the furnace tubes, the main concern and limitation to operating lifecycle o steam cracking units is the coke formation in the furnace tubes. The reactions carry out under high temperatures, between 500 oC to 700 oC according to the characteristics of the feed (inlet temperature). For heavier feeds like gas oil, is applied lower temperature aiming to minimize the coke formation, the combination of high temperatures and low residence time are the main characteristic of the steam cracking process.

As quoted above, some technology developers are dedicating his efforts to develop commercial crude to chemicals refineries. Figure 7 presents the concept of crude to chemicals refining scheme by Chevron Lummus Company.

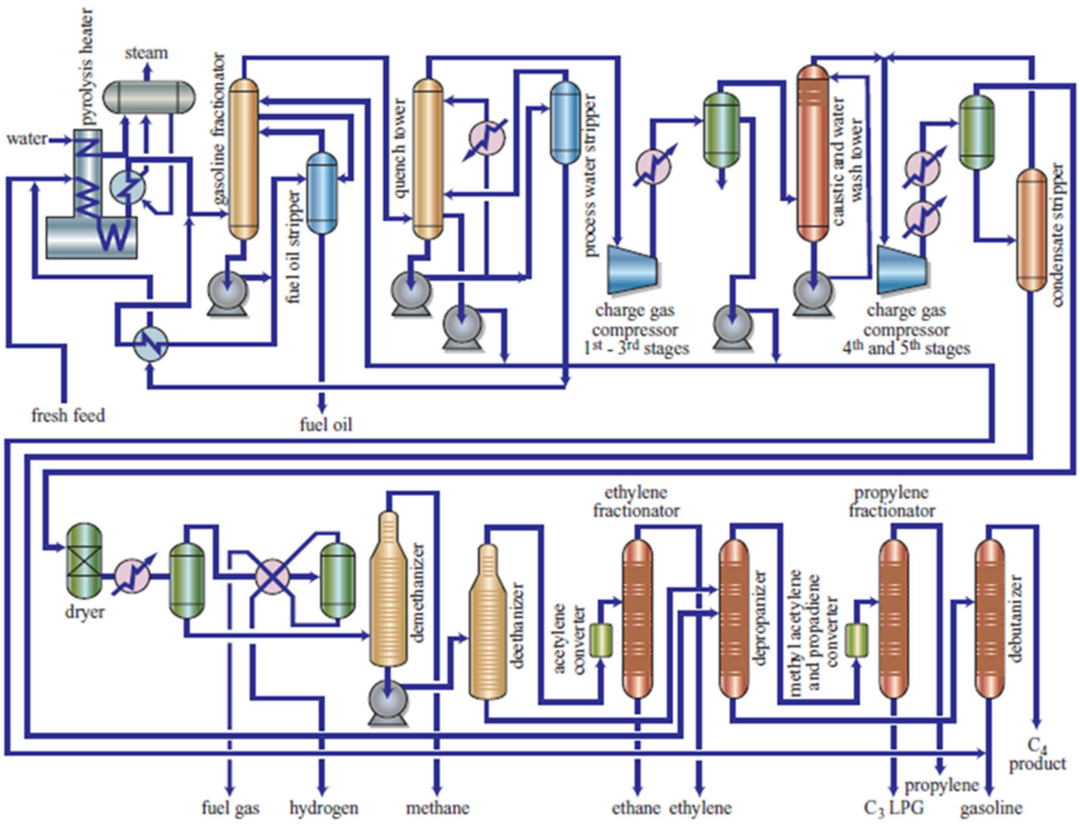


Figure 6 – Typical Naphtha Steam Cracking Unit (Encyclopedia of Hydrocarbons, 2006)

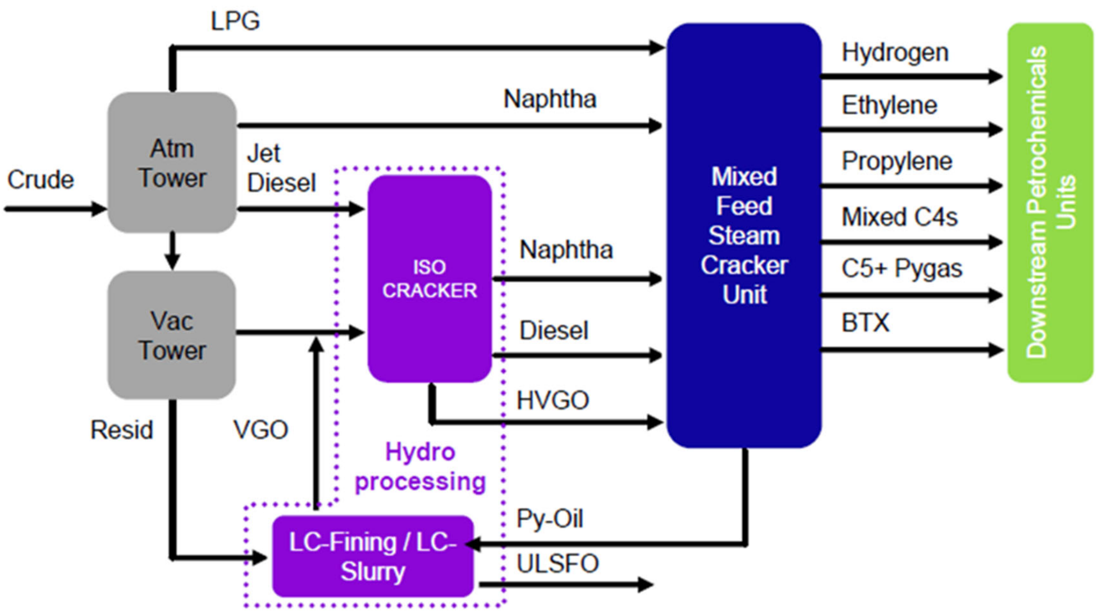


Figure 7 – Crude to Chemicals Concept by Chevron Lummus Company (Chevron Lummus Global Company, 2019)

Another great refining technology developers like UOP, Shell Global Solutions, ExxonMobil, Axens, and others are developing crude to chemicals technologies, reinforcing that this is a trend in the downstream market.

As aforementioned, face the current trend of reduction in transportation fuels demand at the global level, the capacity of maximum adding value to crude oil can be a competitive differential to refiners. Due to the high capital investment needed for the implementation that allows the conventional refinery to achieve the maximization of chemicals, capital efficiency becomes also an extremely important factor in the current competitive scenario as well as the operational flexibility related to the processed crude oil slate.

Although the advantages presented by closer integration between refining and petrochemical assets, it's important to understand that the players of downstream industry are facing with a transitive period where, as presented in Figure 1, the transportation fuels are responsible by great part of the revenues. In this business scenario, it's necessary to define a transition strategy where the economic sustainability achieved by the current status (transportation fuels) needs to be invested to build the future (maximize petrochemicals). Keep the eyes only in the future or only in the present can be a competitive mistake.

## CONCLUSION

The synergy between refining and petrochemical processes raises the availability of raw material to petrochemical plants and makes the supply of energy to these processes more reliable at the same time ensures better refining margin to refiners due to the high added value of petrochemical intermediates when compared with transportation fuels. The development of crude to chemicals technologies reinforces the necessity of closer integration of refining and petrochemical assets by the brownfield refineries aiming to face the new market that tends to be focused in petrochemicals against transportation fuels, it's important to note the competitive advantage of the refiners from Middle East that have easy access to light crude oils which can be easily applied in crude to chemicals refineries. As presented above, crude oil to chemicals refineries are based on deep conversion processes that requires high capital spending, this fact can put under pressure the refiners with restrict access of capital, again reinforcing the necessity to look for close integration with petrochemical sector aiming to achieve competitiveness.

As aforementioned, crude oil to chemicals strategy can lead the refiners to achieve a more profitable market with some enter barriers related to the high capital investment that limit the players, allowing these players to enjoy some characteristics of the "Blue Ocean Strategy" as defined by the authors W. Chan Kim and Renée Mauborge.

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# Key Performance Indicators and Performance Report Criteria for Process Plant Alarm Management System

Praveen Nagenderan C

**KEY PERFORMANCE INDICATORS**

It is necessary to define a set of quantitative key performance indicators (KPIs) to define performance levels for an alarm system. Two categories of data in a typical alarm system are Alarm records (i.e. dynamic or real-time data) and alarm attributes. Both categories are valuable in alarm system performance measurement and are subject to different analyses. Alarm records contain alarm-related information and are produced by the system when an alarm occurs. Alarm attributes make up the underlying structure which is necessary so that alarm records are produced, including alarm types, alarm setpoints, alarm priorities, dead bands, and similar items. All KPIs should be evaluated and compared with both industry standards and site set metrics. The site shall set its metrics for continual improvement towards the industry standards. Instrument Manager to fix site metrics every month based on the previous month's alarm system performance and considering continual improvement towards the industry standards.

1.) Average Alarm Rate:

Analysis of alarm rate i.e annunciated alarm rate is a good indicator of the overall health of the alarm system. Records should be analyzed every 15 days to analyze the alarm system performance. 6 Alarms per hour (Average) or 1 Alarm per 10 mins (Average) are very likely to be acceptable whereas 12 Alarms per hour (Average) or 2 Alarms per 10 min (Average) are maximumly manageable as per EEMUA 191 and ISA 18.2 standards.

2.) Peak Alarm Rate:

Alarm rates can exceed the operator capability for effective alarm response and result in missed alarms. For peak alarm rate analysis, annunciated alarms are counted in regular 10-minute intervals. The recommended target is less than 1% of the 10-minute interval should contain more than 10 alarms. The number of intervals exceeding 10 alarms and the magnitude of the highest peaks should be reported.

3.) Number of Alarm Floods:

Alarm floods are variable duration periods of alarm activity with annunciation rates likely to exceed operator response capability. Alarm flood calculations involve the determination of adjacent time periods where the alarm rate is high thus producing an overall flood event. The start of an alarm flood is indicated by a high alarm rate (Example: An alarm rate that exceeds 10 alarms per 10 minutes) and the end of an alarm flood is indicated by a return to reduced alarm rate. (Example: An alarm rate of fewer than 5 alarms per 10 minutes). Recommended target is an alarm system that should be in flood for less than ~1% of the time. Improvements to the alarm system and process operation may be indicated by the analysis of alarm floods. Analysis should include the Number of alarm floods, Duration of each alarm flood, Alarm count in each alarm flood, and Peak alarm rate for each alarm flood

4.) Frequently occurring alarms:

Relatively few individual alarms often produce a large percentage of the total alarm system load. The most frequent alarms should be identified from the alarm history for a period of days and to be analyzed for improvement. Alarms that contribute more than 20% of the total alarm rate are to be considered as “Frequently occurring alarms”. Action plan to be set at the review meeting for the identified “Frequently occurring alarms”.

5.) Stale Alarms:

Alarms that remain annunciated continuously for an extended duration i.e 24 hours can be considered as “Stale Alarms”. Identified stale alarms should be review at the review meeting and an appropriate action plan to be set to avoid stale alarms. The target rate is less than 5 % of total alarms annunciated on any day with an action plan to address.

6.) Annunciated Alarm Priority Distribution:

Effective use of alarm priority can enhance the ability of the operator to manage alarms and provide a response. The total number of alarms annunciated per priority to be taken and analyzed for improvement. Alarms annunciated priority distribution shall be ~80% for Low class, ~15% Medium, ~5% High, and ~1% Critical. These priority distributions are applicable for the only process-related alarm and its defined classes. Other categories are excluded from the analysis.

7.) Number of Alarm occurrences for a particular group of systems:

Each alarm configured in the system is to be provided with a group name. The number of alarm occurrences for a particular group of systems to be identified from the daily list of annunciated alarm lists.

8.) Number of Chattering and Fleeting Alarms:

Chattering alarm repeatedly transitions between the active state and the not active state in a short period. Fleeting alarms are similar short-duration alarms that do not immediately repeat. In both cases, the transition is not due to the result of operator action. A chattering alarm can generate hundreds or thousands of records in a few hours. This results in a significant distraction for the operators. Chattering alarms are often high in the listing of the most frequent alarms. Target performance acceptance criteria are there is a no-term acceptable quantity of chattering or fleeting alarms.

**PERFORMANCE REPORT**

Generation of performance reports provides an accurate picture of the alarm system performance. The facility shall generate alarm system performance report monthly apart from the bi-weekly review meetings on the alarm system. Monthly alarm system performance report to be generated by System/ Instrument Engineer.

- An alarm system performance report should include the below-mentioned items:
- Alarm rates (Daily analysis)
- Peak Alarm Rate (Daily analysis)
- Percentage of time when the alarm system is in flood condition (Daily analysis)
- Frequently occurring alarms (Daily Analysis)
- Annunciated Alarm priority distribution percentage (Daily Analysis)
- Alarms Suppressed by the operator (Daily Analysis)
- List of shelved alarms with duration (Daily Analysis)
- List of out-of-service alarms with duration (Daily Analysis)
- Stale Alarms (Daily Analysis)
- Chattering Alarms (Daily Analysis)
- Details of System alarms (Daily Analysis)
- Alarms setpoint changes
- Alarm group changes
- Alarms priority changes
- Details of Alarm rationalization taken up
- Review meetings outcome
- Progress against the resolution of an identified nuisance alarm list
- Action plans to improve performance compared to KPIs and progress of those plans

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Safety Talk

# Hand Tool Safety

Chris Palmisano

Tool accidents can be prevented if everyone who uses hand tools would follow three simple rules:

- Choose the right tool for the job.
- Be sure the tool is in good condition.
- Use the tool correctly.

After choosing the right tool for the job, inspect it. Ask yourself, is the tool in good condition?

Always use all tools the way they were meant to be used. As an example, never use a wrench as a hammer. Another example may be, don't using a file as a a pry bar. Files ate made of a brittle metal that can crack and cause a serious injury and never use a file without a handle.

Never use a screwdriver in place of a pry bar or chisel. Use the screwdriver that fits the screw. Have points dressed if bent, worn or broken. Use an insulated handle screwdriver on all electrical work.

When using a hammer, be sure it has a securely handle suited to the type of head. If the handle is wooden or fiberglass, watch out for splinters. Remember that carpenter type claw hammers are designed for driving or drawing nails. They should never be used to strike a cold chisel or other hardened steel tools.

If the tool is defective, turn it or obtain a replacement. You are responsible for the inspection of all tools, and you should tag or mark any defective tools for immediate repair so they aren't accidentally used.

Even a good tool must be used properly to be safe for the user.

Here are some precautions to take when using some common tools.

1. When using hand saws, keep them sharp with teeth properly set and clean. Be careful when using your thumb as a guide to start a cut.
2. When using punches and chisels, have the head dressed if it's mushroomed before using it, wear your eye and hand protection.
3. Discard worn wrenches having jaws that will not hold and be sure the adjusting screws are free of rust.

In closing, a bad tool or using the wrong tool for the job can be dangerous, so keep your tools maintained and in good shape, keep them clean and organized and you are less likely to have an accident or cause a coworker harm with a hand tool.

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# Exploring LPG Cylinders for Medical Oxygen | A Preliminary Study

Jayanthi Vijay Sarathy

The following article is a study to explore the usage of LPG cylinders for medical oxygen in times of medical emergencies. The study aims at understanding how long medical oxygen can be supplied to cater to patients requiring supply between 0.5 lit/min to 2 lit/min.

General Notes & Assumptions

1. Medical Oxygen composition is taken to contain 90% O2, 5% N2 and 5% Ar.
2. The LPG cylinder considered has a 33.3 litre water capacity, storing 14.2 kg of LPG.
3. The analysis is performed as a vessel with an orifice discharging the fluid to the down-stream and considering patients requiring oxygen in the range of 0.5 lit/min and 2 lit/min. The orifice discharge coefficient [Cd] is taken as 0.62.
4. Considering a cylinder pressure cap of 16.9 kg/cm2, the pressure cap for the study is taken as 16.0 bara at 250C. The pressure at which medical oxygen is delivered is taken as 1.01325 bara.
5. For the analysis, an isothermal blowdown condition is taken assuming the breathing process from the medical oxygen cylinder takes sufficiently long time and the gas temperature also does not change with time. Hence heat is absorbed through the walls such that the cylinder temperature is close to ambient temperature.

## GOVERNING RELATIONSHIPS

To estimate the blow down time, a transient study is performed. To check if choked flow exists, the following condition is applied,

$$\frac{P_{cyl}}{P_{atm}} \geq \left[\frac{k+1}{2}\right]^{\frac{k}{k-1}} \quad \text{(A)}$$

Where,

Pcyl = Cylinder Pressure [bara]

Patm = Atmospheric Pressure [bara]

k = ratio of specific heats [Cp/Cv] [-]

The blowdown time can be estimated as,

$$P_{cyl} = P_0 exp\left[-\frac{t}{\tau}\right] \quad \text{(B)}$$

$$\tau = \left[\frac{V_{cyl}}{C_d \times A \times \left[\frac{2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \times \left[\frac{k \times R \times T_{cyl}}{MW}\right]^{1/2}}\right] \quad \text{(C)}$$

Where,

t = Discharge Time Constant [sec]

Pcyl = Cylinder Pressure [bara]

P0 = Cylinder Initial Pressure [bara]

## DESIGN DATA & RESULTS

The input data and results for 0.5 lit/min is as follows,

**Table 1. Input Data and Results for 0.5 lit/min**

| Parameter | Value | Unit |
|---|---|---|
| Effective Cylinder Volume [V] | 0.0333 | $m^3$ |
| Medical Oxygen MW | 32.2 | kg/kmol |
| Initial Pressure [$P_0$] | 16 | bara |
| Initial Temperature [$T_0$] | 25 | $^0C$ |
| Oxygen k [$C_p/C_v$] | 1.395 | - |
| Choked Flow Exists or Not | Choked Flow | |
| Compressibility Factor [Z] | 0.9902 | - |
| Oxygen Density [r] | 20.99 | $kg/m^3$ |
| Mass of O2 in Cylinder [m] | 0.699 | kg |
| Orifice Throat Diameter [d] | 0.30 | mm |
| Orifice Throat CSA [A] | 7.0926E-08 | $m^2$ |
| Discharge Coefficient [$C_d$] | 0.62 | - |
| Speed of Sound [C] | 327.7 | m/s |
| Discharge Time Constant [t] | 3,991 | sec |
| Mass Flow Rate [$m_g$] | 0.0002 | kg/s |
| Volumetric Flow Rate | 0.000008 | $m^3/s$ |
| Required Vol. Flow Rate | 0.50 | lit/min |

The input data and results for 2 lit/min is,

Table 2. Input Data and Results for 2 lit/min

| Parameter | Value | Unit |
|---|---|---|
| Orifice Throat Diameter [d] | 0.60 | mm |
| Orifice Throat CSA [A] | 2.8334E-07 | m² |
| Discharge Time Constant [ t] | 999 | sec |
| Mass Flow Rate [$m_g$] | 0.0007 | kg/s |
| Volumetric Flow Rate | 0.000033 | m³/s |
| Required Vol. Flow Rate | 2.00 | lit/min |

Plotting a graph between cylinder pressure and Time for both cases of 0.5 lit/min and 2 lit/min,

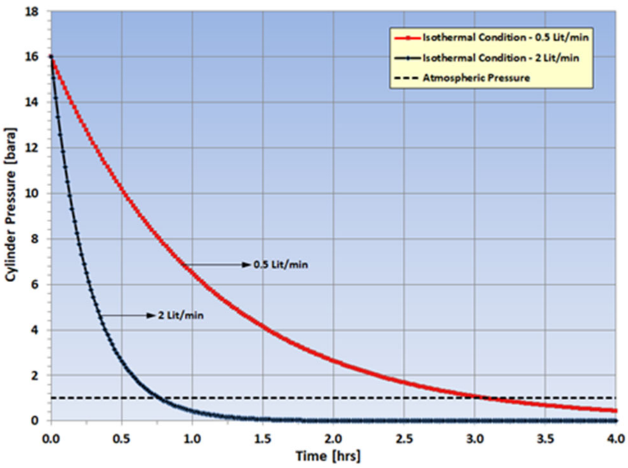


Figure 1. Cylinder Pressure vs. Time

From the above figure, the cylinder pressure beginning from an initial pressure of 16 bara reaches 1 atm in about 3 hours for a discharge rate of 0.5 lit/min and about 45 min for the case of 2 lit/min.

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## APPENDIX A: DERIVATIONS OF EXPRESSIONS

$$\frac{dm}{dt} = -m_g \qquad (1)$$

'm' = mass of gas in the cylinder, expressed as,

$$m = \rho_{cyl} \times V_{cyl} \qquad (2)$$

Where,

$r_{cyl}$ = Density of gas in cylinder [kg/m$^3$]

$V_{cyl}$ = Volume of gas in cylinder [m$^3$]

Whereas, $m_g$ is mass flow rate at choked flow conditions is expressed as,

$$m_g = C_d \times A \times \rho_c \times v_c \qquad (3)$$

Where,

$C_d$ = Orifice Discharge Coefficient [-]

A = Orifice Cross-sectional Area [m$^2$]

$r_c$ = Density at choked flow at throat [kg/m$^3$]

$v_c$ = Speed of Sound [m/s]

The speed of sound can be estimated as,

$$v_c = \left[\frac{k \times R \times T_c}{MW}\right]^{1/2} \qquad (4)$$

Where,

MW = Fluid Molecular Weight [kg/kmol]

$T_c$ = Temperature at choked conditions [K]

For a reversible adiabatic expansion, the fluid density at the orifice throat can be related to the fluid density in the cylinder as,

$$\frac{\rho_c}{\rho_{cyl}} = \left[\frac{2}{k+1}\right]^{\frac{1}{k-1}} \qquad (5)$$

$$\frac{T_c}{T_{cyl}} = \left[\frac{\rho_c}{\rho_{cyl}}\right]^{k-1} \qquad (6)$$

Or, $$T_c = T_{cyl} \times \left[\frac{2}{k+1}\right] \qquad (7)$$

Therefore the speed of sound at cylinder conditions can be expressed as,

$$v_c = \left[\frac{2 \times k \times R \times T_{cyl}}{MW \times (k+1)}\right]^{1/2} \qquad (8)$$

Therefore the mass flow rate at choked flow related to cylinder process conditions becomes,

$$m_g = C_d \times A \times \rho_{cyl} \left[\frac{2}{k+1}\right]^{\frac{1}{k-1}} \times \left[\frac{2 \times k \times R \times T_{cyl}}{MW \times (k+1)}\right]^{1/2} \quad (9)$$

Or

$$m_g = C_d \times A \times \rho_{cyl} \left[\frac{2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \times \left[\frac{k \times R \times T_{cyl}}{MW}\right]^{1/2} \quad (10)$$

Where,

R = Gas Constant [8.314 $m^3$.bar/kmol.K]

The cross-sectional area of the orifice is,

$$A = \frac{\pi}{4} \times d_{orifice}^2 \quad (11)$$

Where,

$d_{orifice}$ = Orifice diameter [m]

Therefore solving for blowdown time,

$$V_{cyl} \times \frac{d\rho_{cyl}}{dt} = C_d \times A \times \rho_{cyl} \left[\frac{2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \times \left[\frac{k \times R \times T_{cyl}}{MW}\right]^{1/2} \quad (12)$$

Rearranging the above,

$$-\left[\frac{V_{cyl}}{C_d \times A \times \left[\frac{2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \times \left[\frac{k \times R \times T_{cyl}}{MW}\right]^{1/2}}\right] \frac{d\rho_{cyl}}{dt} = \rho_{cyl} \quad (13)$$

Simplifying the expression by taking a discharge time constant [t],

$$\tau = \left[\frac{V_{cyl}}{C_d \times A \times \left[\frac{2}{k+1}\right]^{\frac{k+1}{2(k-1)}} \times \left[\frac{k \times R \times T_{cyl}}{MW}\right]^{1/2}}\right] \quad (14)$$

Substituting and solving for the blowdown time,

$$\frac{d\rho_{cyl}}{dt} = -\frac{\rho_{cyl}}{\tau} \quad (15)$$

$$\int_{\rho_0}^{\rho_{cyl}} \frac{d\rho_{cyl}}{\rho_{cyl}} = -\int_{t=0}^{t=t} \frac{dt}{\tau} \quad (16)$$

$$ln\left[\frac{\rho_{cyl}}{\rho_0}\right] = -\frac{t}{\tau} \quad (17)$$

$$\rho_{cyl} = \rho_0 exp\left[-\frac{t}{\tau}\right] \quad (18)$$

Applying ideal gas law to convert densities to pressures,

$$P_{cyl} = P_0 exp\left[-\frac{t}{\tau}\right] \quad (19)$$

## Appendix B: MS Excel Calculations

| Cylinder Blow Down Time - 0.5 Lit/min | | |
|---|---|---|
| **Domestic 14.2 kg LPG Cylinder** | | |
| Effective Cylinder Volume [V] | 0.0333 | $m^3$ |
| Oxygen [$O_2$] MW | 32.2 | kg/kmol |
| Initial Pressure [$P_0$] | 16 | bara |
| Initial Temperature [$T_0$] | 25 | $^oC$ |
| | 298.15 | K |
| Oxygen k [Cp/Cv] | 1.395 | - |
| Choked Flow Exists or Not | Choked Flow | |
| Compressibility Factor [Z] | 0.9902 | - |
| $O_2$ Std. Density [1 atm, $20^oC$] | 1.316 | kg/$m^3$ |
| Oxygen Density [r] | 20.99 | kg/$m^3$ |
| Mass of $O_2$ in Cylinder [m] | 0.699 | kg |
| Orifice Throat Diameter [d] | 0.30 | mm |
| Orifice Throat CSA [A] | 7.0926E-08 | $m^2$ |
| Discharge Coefficient [$C_d$] | 0.62 | - |
| Speed of Sound [C] | 327.7 | m/s |
| Discharge Time Constant [ τ] | 3991 | sec |
| Mass Flow Rate [m_rate] | 0.0002 | kg/s |
| Volumetric Flow Rate | 0.000008 | $m^3$/s |
| Required Vol. Flow Rate | **0.50** | lit/min |
| **Cylinder Blow Down Time - 2 Lit/min** | | |
| Orifice Throat Diameter [d] | 0.60 | mm |
| Orifice Throat CSA [A] | 2.8334E-07 | $m^2$ |
| Discharge Time Constant [ τ] | 999 | sec |
| Mass Flow Rate [m_rate] | 0.0007 | kg/s |
| Volumetric Flow Rate | 0.000033 | $m^3$/s |
| Required Vol. Flow Rate | **2.00** | lit/min |

**AUTHOR**

Vijay Sarathy holds a Master's Degree in Chemical Engineering from Birla Institute of Technology & Science (BITS), Pilani, India and is a Chartered Engineer from the Institution of Chemical Engineers, UK. His expertise over 14 years of professional experience covers Front End Engineering, Process Dynamic Simulation and Subsea/Onshore pipeline flow assurance in the Oil and Gas industry. Vijay has worked as an Upstream Process Engineer with major conglomerates of General Electric, ENI Saipem and Shell.

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