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Outlets and Applications for Natural Gas

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This is the seventh article in a series by OTC specialists and partners on natural gas (NG) and liquefied natural gas (LNG).

The series comprises the following articles which are scheduled for publication on the dates listed:

1. Overview of the LNG industry – September 2020
2. Traditional gas transport modes – November 2020
3. Safe and clean storage of natural gas – January 2021
4. Alternative modes of natural gas transport – March 2021
5. Overview of LNG technologies – May 2021
6. Comparison of inland NG/LNG and imported LNG – June 2021
7. Outlets and applications for natural gas – August 2021
8. Gas for power generation – September 2021
9. Small scale versus large scale LNG – November 2021
10. Gas utilisation in transport – December 2021

These articles are published over a period of 16 months and will be interspersed with articles related to aspects of project management and renewable energy.

Introduction

South Africa's energy sector has been in a state of insecurity for many years, and this will probably continue into the foreseeable future. Carbon emissions are high due to an over-reliance on coal as feedstock.

This sets the scene for a greater dependence on gas as an energy source. Gas advocates have also long argued that gas can serve as a 'bridging fuel' until renewable energy can be commercially developed. It is interesting to note that the latest South African Integrated Resource Plan (IRP2019) shows a 63% decline in the forecast use of gas for electricity generation by 2030 (Dept. of Mineral Resources and Energy, 2019). It seems as if the planned gas-to-power programme has been adjusted downwards in the short to medium term, considering the availability of gas resources and applicable infrastructure. The addition of natural gas to the country's energy mix will rejuvenate an overburdened energy infrastructure and reduce cyclical energy shortfalls.

Natural gas is an excellent fuel and energy source and deserves a larger percentage of the South African energy market than the current 3,2% (Veitch, 2018). In this article, we consider the terminology used for natural gas, and describe the residential, commercial, and industrial outlets and/or applications for natural gas.

Natural gas basics

Opening remarks

Natural gas (NG) occurs naturally as a fossil fuel, is a by-product of oil refineries, and can be generated by purifying biogas from landfills or bio-digesters. In all these cases the active molecule is methane (CH_4). NG is the earth's cleanest burning hydrocarbon. Its combustion does not produce ash residues, sulphur oxides, and only negligible nitrous oxides. This sets it apart from all the other fossil fuels.

NG terminology

Raw NG as found in nature is predominantly methane, but may also contain some ethane, butane, propane, pentane, and hexane gases. Collectively, these are known as Natural Gases, as shown in Figure 1. Contaminants can include nitrogen, carbon dioxide, sulphur compounds, and water vapour. Raw natural gas is treated in a series of processes, including phase separation, CO_2 scrubbing, dehydration, sulphur removal, refrigeration, and finally, liquefaction to produce liquefied natual gas or LNG. LNG is a clear, colourless, and non-toxic liquid that forms naturally when NG is cryogenically cooled to -162°C.

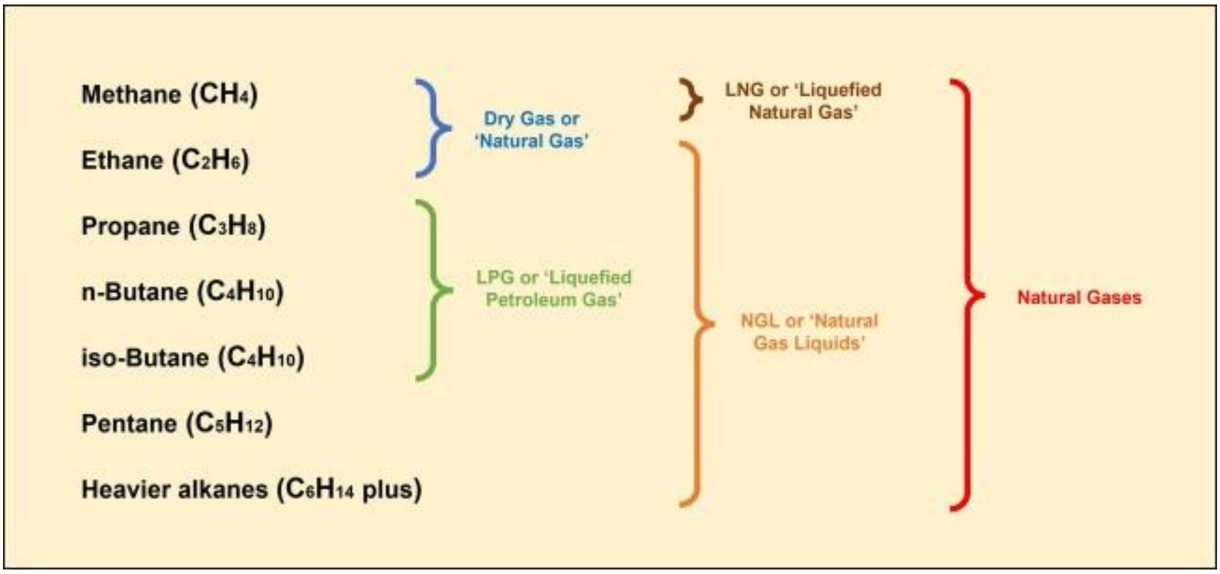

Figure 1: Natural gas terminology (adapted from Miller, 2018)

Dry gas is a common term for NG which contains no liquid hydrocarbons under pressure. It consists largely of methane but can also contain some ethane**.** If the intention is to liquefy the NG, it is preferable to reduce the ethane content to a minimum. Propane, together with the two butane isomers, is marketed as liquefied petroleum gas or LPG. Pentane and heavier products can be used as a liquid fuel or as solvents.

Compressed natural gas or CNG is simply dry gas that is stored under pressure while remaining in its gaseous form. The typical storage pressure of CNG is 200 to 250 bar. This high pressure reduces the volume of the CNG to less than 1% of its volume at standard atmospheric pressure.

NG is transported by pipeline as dry gas, or in cylinders as either CNG or LNG. The chosen mode of transport is a function of volume, distance, and existing infrastructure.

NG applications

Different authors use different categories to describe NG markets, uses, and applications. One approach is to use five categories, namely the electric power sector, the transport sector, the industrial sector, the commercial sector, and the domestic sector (EIA, 2021). My preference is to group the electric power sector with the industrial sector, and the transport sector with the commercial sector. This gives three sectors for NG applications, as shown in Figure 2.

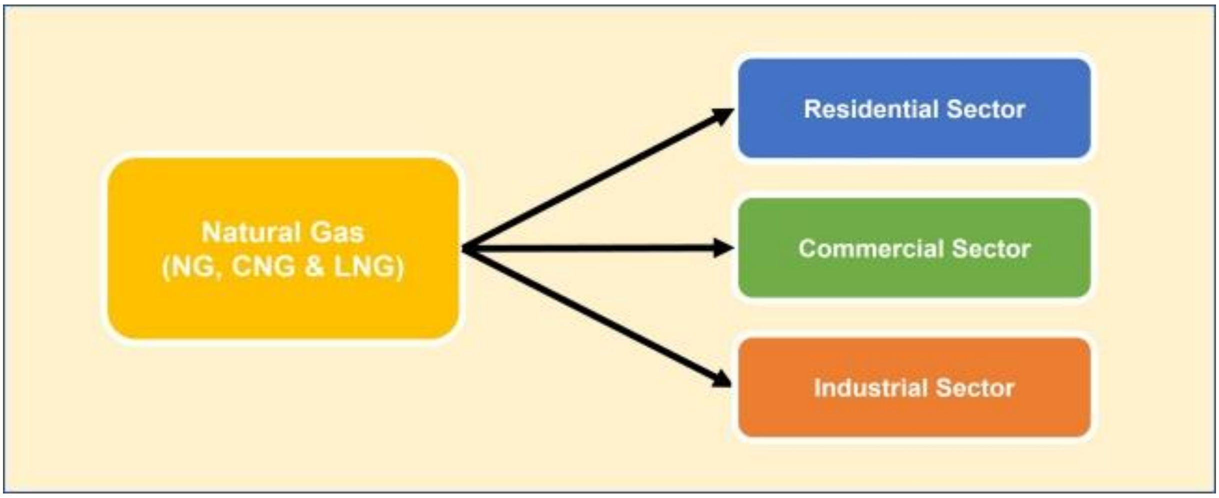

Figure 2: Categories of NG applications

Each of these sectors is discussed in more detail in the sections that follow. It will become obvious that there is substantial overlap between sectors.

Residential applications

Opening remarks

In the domestic sector, NG is used for heating and cooking, as shown in Figure 3. Figure 3 is typical of the graphics used for each of the sectors, and shows the category of usage, the specific application, and the final product resulting from the application.

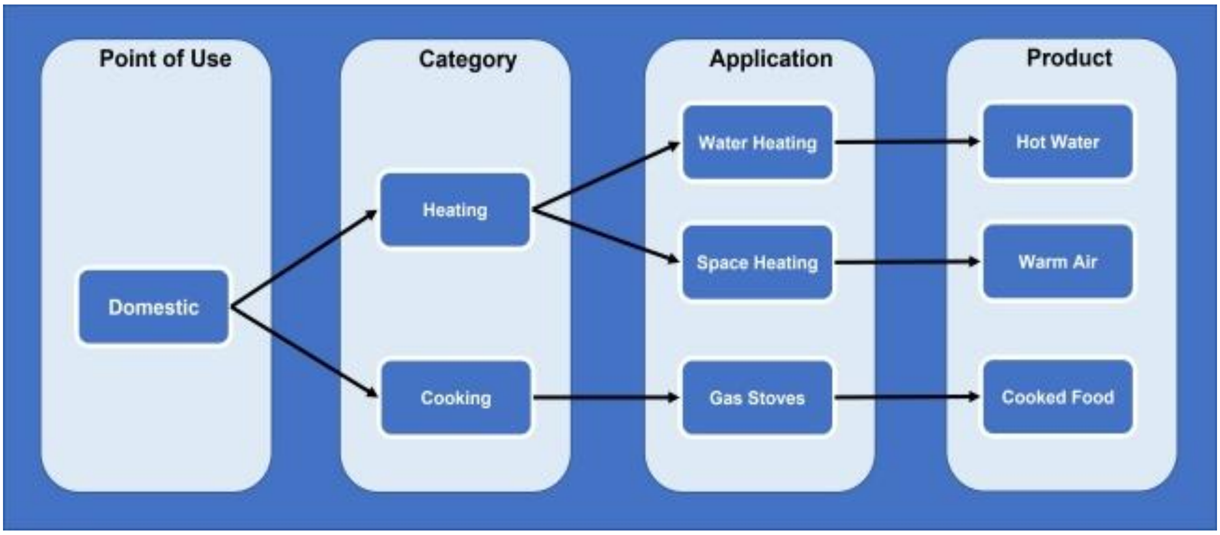

Figure 3: Residential applications of natural gas

To supply NG to residential users, a gas distribution network that connects the households to the supply station must be deployed. However, pipeline infrastructure is economically viable in urban centres due to the dense populations. Alternatively, modular containers of LPG can be used.

Each of these categories and applications of NG in the domestic sector is discussed in more detail in the sections that follow.

Heating

The penetration of NG as heating fuel in urban and rural areas depends on its price compared to the available alternatives like electricity, coal, wood, and kerosene.

Domestic applications for heating include both water heating and space heating. Water heating makes up about 30% of the average household energy bill. Two types of domestic water heaters are available, namely tankless heaters and gas water heater tanks. A tankless gas water heater works when you open a hot water tap and a sensor detects the flow. The gas burner fires, and the heat exchanger warms the flowing water. An advantage of this type of heater is that it can endlessly supply hot water.

A gas water heater tank works by heating water and storing it until needed. Hot water is drawn from the top of the tank and replaced with cold water at the bottom, since warm water rises. When the tank water temperature drops below the thermostat set-point, the water heater works by having the burner run until the temperature recovers to the set-point.

Space heating can be accomplished by circulating hot water through pipes installed in the house or by blowing hot air from a gas-fired furnace through interconnected ducting. Room space heaters heat the room they are in and do not use a heat distribution system. Modern gas powered heaters can heat large areas very quickly and refined combustion processes mean extremely low levels of emissions. Using gas heaters not only saves on electricity consumption but allows the user access to instant heat at the touch of a button.

Cooking

Electric cooking systems are more popular than gas cooking systems because electricity is more widely available as a source of power than piped NG or LPG cylinders. The initial installation of a gas cooking system can be expensive as there is the need for installing the gas pipeline to the gas stove, as well as the fact that gas cookers are generally more expensive than comparable electric cookers.

Gas cooking systems heat up more quickly and heat can be controlled more precisely than with electricity, which makes it the preferred option for chefs. Operating cost can be significantly lower with gas, but the price difference depends on the country where you live. However, NG is almost always cheaper than electricity. Gas cooking carries a slightly higher risk than electricity as gas leaks can cause explosions.

Commercial applications

Opening remarks

Commercial applications of natural gas are shown in Figure 4. Applications cover all the residential applications described in the previous section, plus several others. Note that ‘Transport’ is included here as one of the categories of commercial applications.

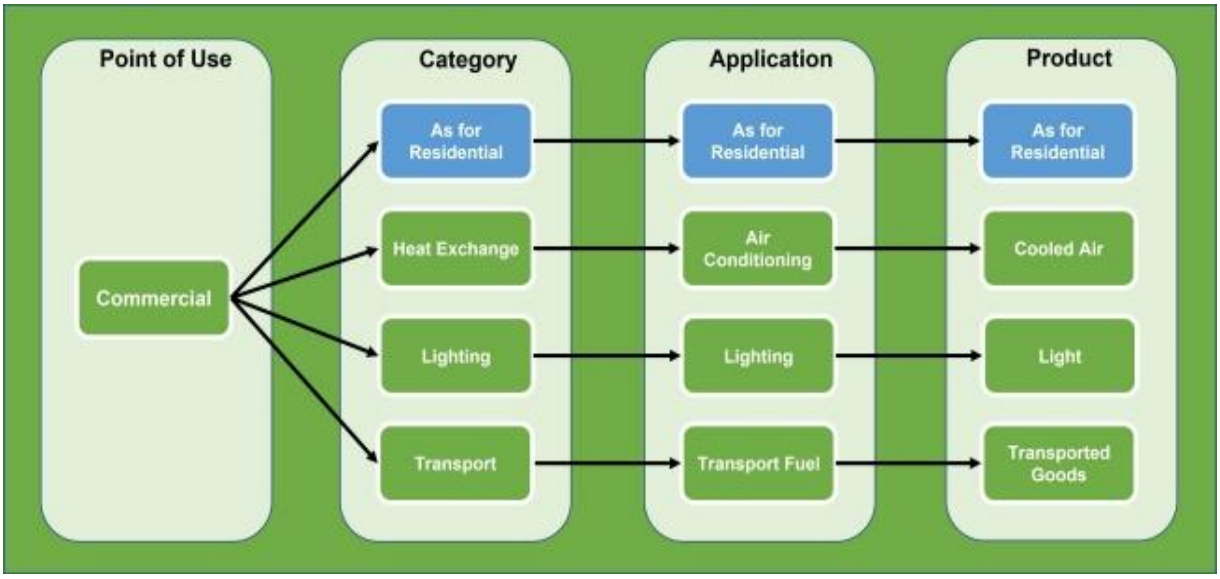

Figure 4: Commercial applications of natural gas

Where commercial applications for natural gas overlap with residential applications, the reader is referred to the previous section. The non-residential applications are discussed in more detail in the sections that follow.

Heat exchange

The latest NG-based air conditioning technology is much more advanced than the earlier technology, and these days it provides superior energy efficiency than the older systems did. NG air conditioning is offered in a variety of sizes to meet most customers' needs in all sizes of commercial or industrial facilities.

NG-fired air conditioners for commercial use are mostly direct-fired absorption chillers. An absorption chiller uses a refrigerant, absorbent, and heat to create a cooling effect. Cooling is accomplished with the removal of heat through evaporation of a refrigerant at low pressure and the rejection of heat through the condensation of the refrigerant at a higher pressure. Air-cooled chillers use environmentally safe ammonia as the refrigerant and water as the absorbent.

Lighting

Gas lighting is the production of artificial light from combustion of a gaseous fuel, such as hydrogen, methane, propane, butane, and acetylene. Before electricity became sufficiently widespread and economical to allow for public use, gas was the most popular means of outdoor and indoor lighting in cities and suburbs. Early gas lights had to be lit manually, but many later designs are self-igniting.

The use of NG lights for indoor lighting is nearly extinct, although it can be used to create a desired ambiance in restaurants and other public places. Gas lighting is still in common use for camping lights. Small portable gas lamps, connected to a portable gas cylinder, are a common item on camping trips.

Transport

CNG and LNG are used as fuel in the transportation sector in vehicles such as cars, trucks, locomotives, and as bunker fuel for ships. At the end of 2019, there were over 28 million NG-fuelled land-based motor vehicles and over 33 000 NG fuelling stations in the world (NGV Global, 2019). Nearly all vehicles that use NG as a fuel are in government and commercial vehicle fleets. The top three countries for NG-fuelled motor vehicles in order are China, Iran, and India. Approximately 1% of these vehicles are in Africa.

NG is becoming an increasingly mainstream alternative to diesel for heavy-duty and long-haul transport. Fleet operators and policymakers alike are attracted to the lower fuel cost and the smaller carbon and air quality footprints. CNG and dual-fuel trucks, i.e., trucks that can run on both CNG and diesel, are currently available in South Africa (Clarke, 2020). CNG conversion kits, costing between R180 000 and R250 000 (US$12 000 and US$17 000), are also available to convert a ‘normal’ diesel truck into a dual-fuel truck. The CNG kit can be removed from the vehicle at the end of its economic life and transferred to a second vehicle. Unfortunately, CNG is currently not readily available throughout southern Africa. It is currently only available in specific locations in Gauteng, Mpumalanga, Free State and KwaZulu-Natal. One of the benefits of having a dual-fuel vehicle is that, should the CNG run out and not be available, the vehicle can still run on the diesel fuel in its standard fuel tanks.

LNG powered vehicle technology has matured over the last 15 years. Technology improvements have all contributed to this. Engine manufacturers, such as Cummins and Caterpillar, have also assisted by providing engines for LNG. LNG powered vehicles have range and refuelling times comparable to diesel.

Rail transport is also a potential LNG application. LNG to replace diesel for locomotives has increased substantially in the past few years and LNG powered locomotives are already in use in other countries. Ships with short repetitive routes are also a viable LNG use. Ferries are a prime example of this application.

The last article in this series on NG, scheduled for December 2021, will deal with the use and benefits of NG as transport fuel in more detail.

Industrial applications

Opening remarks

Industrial applications of natural gas are shown in Figure 5. Applications cover all the commercial applications, which includes the residential applications, described in the previous sections, plus five additional ones.

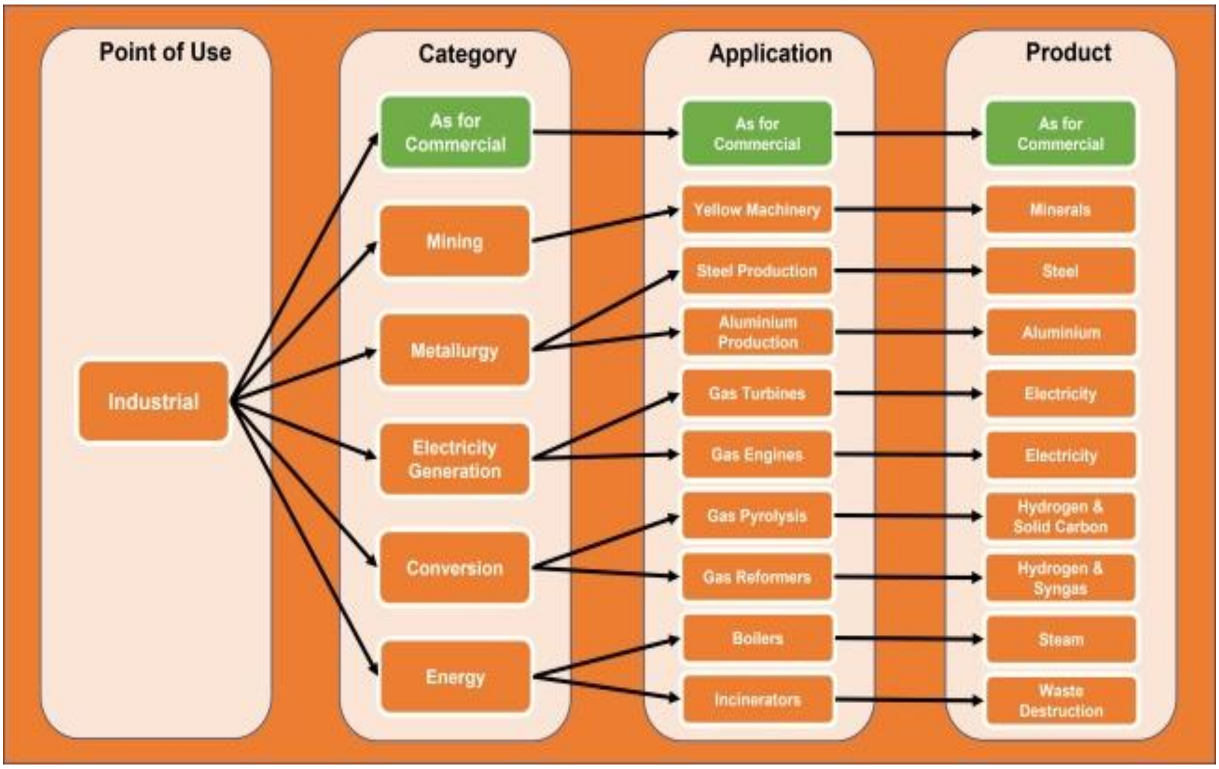

Figure 5: Industrial applications of natural gas

Where industrial applications for natural gas overlap with commercial applications, the reader is referred to the previous sections. The non-residential, and other non-commercial, applications are discussed in more detail in the sections that follow.

Mining

The primary application for NG in mining is also related to transport. The so-called yellow machinery used in especially open-pit mining operations are typically diesel-fuelled. These vehicles are used only on a particular site with short repetitive routes. This makes them ideal for refuelling at a one-site location. Mining companies are increasingly switching over to NG-fuelled yellow machinery to reduce greenhouse gas emissions and fuel cost.

Yellow machinery includes, but is not limited to:

- **Dragline excavators:** Large semi-stationary excavation machines equipped with a bucket and dragline to scoop up overburden or minerals.
- **Excavator shovels:** Also called mechanical shovels. These are self-propelled machines, on tires or tracks, with a structure capable of rotating at least 360° that excavates land, or loads, lifts, rotates and unloads materials by the action of the shovel.
- **Bucket-wheel excavators:** The primary function of bucket-wheel excavators is to act as a continuous digging machine in large-scale open-pit mining operations, removing thousands of tons of overburden a day.
- **Wheel tractor scrapers:** A wheel tractor-scraper (also known as a Turnapull) is a type of heavy equipment used for earthmoving. It has a pan/hopper for loading and carrying material.
- **Bulldozers:** A machine that is mainly used for earthmoving, digging, and pushing other machines. Although the blade allows a vertical movement of elevation, with this machine it is not possible to load materials on trucks or hoppers
- **Mining Trucks:** Mining dump trucks are large-bottom dump trucks, which transport or haul up to 400 t of materials at a time.

Equipment that uses NG as fuel emit 30% less carbon than diesel-fuelled engines.

Metallurgy

Steel can be produced via two main processes, namely by using an integrated blast furnace (BF)/basic oxygen furnace (BOF) or using an electric arc furnace (EAF). Steel producers using the integrated process start with iron ore as feedstock and use coal as a reductant. Producers using the EAF process use steel scrap or direct reduced iron (DRI) as their main raw material. DRI production requires iron ore as feedstock but uses NG in place of coal as reductant. DRI is a high quality alternative to scrap steel for the production superior steel products. NG emits far less CO_2 than coal during the reduction of iron ore.

The production of DRI requires cheap and readily available NG. Regions with low NG prices like the Middle East or North America are big DRI producers, whereas the process is less common in Europe. Seeing that only about 8% of crude iron used for steel-making is currently made using the DRI process (Sowar, Clinton & Ofori, 2013), low NG prices can increase the usage of DRI and contribute meaningfully to decarbonisation of the steel industry.

NG is also used in the manufacture of aluminium. Alumina, or aluminium oxide, is produced from bauxite using the Bayer process. The last step of this process involves calcination of hydrated alumina (aluminium hydroxide) from the precipitation stage at temperatures up to 1100˚C to form anhydrous alumina (aluminium oxide). Calcination is an energy-intensive process, for which the predominant fuel is NG. Metallic aluminium is produced from anhydrous alumina using the Hall–Héroult electrolysis process.

Electricity generation

NG is the cleanest-burning hydrocarbon, producing around half the CO_2 and just one tenth of the air pollutants of coal when burnt to generate electricity. Gas-fired power stations also take much less time to start and stop than a coal-fired plant. This makes NG a good partner to renewable energy sources like solar and wind power, which are only available when the sun shines and the wind blows…

The gas turbine is one of the most efficient options for the conversion of gas fuels to mechanical power or electricity. Gas turbines are a type of internal combustion engine in which burning of an air-fuel mixture produces hot gases that spin a turbine to produce power. The fast-spinning turbine drives a generator that converts a portion of the spinning energy into electricity. More recently, as NG prices have fallen, NG-fuelled gas turbines have been more widely adopted for base-load power generation, especially in combined cycle mode, where waste heat is recovered in waste heat boilers, and the steam so generated is used to power a steam turbine. The gas turbine and steam turbine can be coupled to individual generators or to a single generator. In a combined cycle power plant, thermal efficiency can be as high as 60%.

Another option to generate electricity is the use of NG-fuelled reciprocating internal combustion engines to drive the generators. South African power stations typically have diesel-fuelled engine-driven generators as backup for emergency situations. Replacing the current diesel fuel supply with NG is a cost effective, safe, and clean option. Customers can either replace existing diesel generators with gas generators or convert existing units to dual-fuel.

The next article in this series on NG, scheduled for September 2021, will deal with the use and benefits of NG for the generation of electricity in more detail.

Conversion

The most important raw materials for petrochemicals produced from natural gas are ethane and propane. After methane (which is mostly used for fuel), ethane and propane are the most common organic compounds in natural gas. They are removed during natural gas processing, so the more gas produced, the more ethane and propane are available to make petrochemicals. Ethane's primary application is the production of ethylene and plastics.

Gas pyrolysis is the thermal decomposition of methane in the presence of a catalyst to produce hydrogen and some form of solid carbon product, like carbon black. Upcoming pyrolysis technologies produce different types of solid carbon products like graphite and graphene. Every ton of methane is typically converted to 250 kg of hydrogen and 750 kg of carbon. If all carbon from the pyrolysis process can be beneficially utilised or stored, the produced hydrogen can be classified as green hydrogen. Graphene is used in the production of carbon nanotubes.

Most hydrogen produced today is made via steam-methane reforming, a mature production process in which high-temperature steam (700°C to 1 000°C) is used to produce hydrogen from a methane source, such as NG. In steam-methane reforming, methane reacts with steam at a pressure of 3 to 25 bar in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Steam reforming is endothermic, i.e., heat must be supplied to the process for the reaction to proceed. The final product of this process is syngas, a mixture of hydrogen and carbon monoxide.

Syngas, or synthesis gas, is the preferred feedstock to produce a multitude of other chemical compounds, some of which are illustrated in Figure 6.

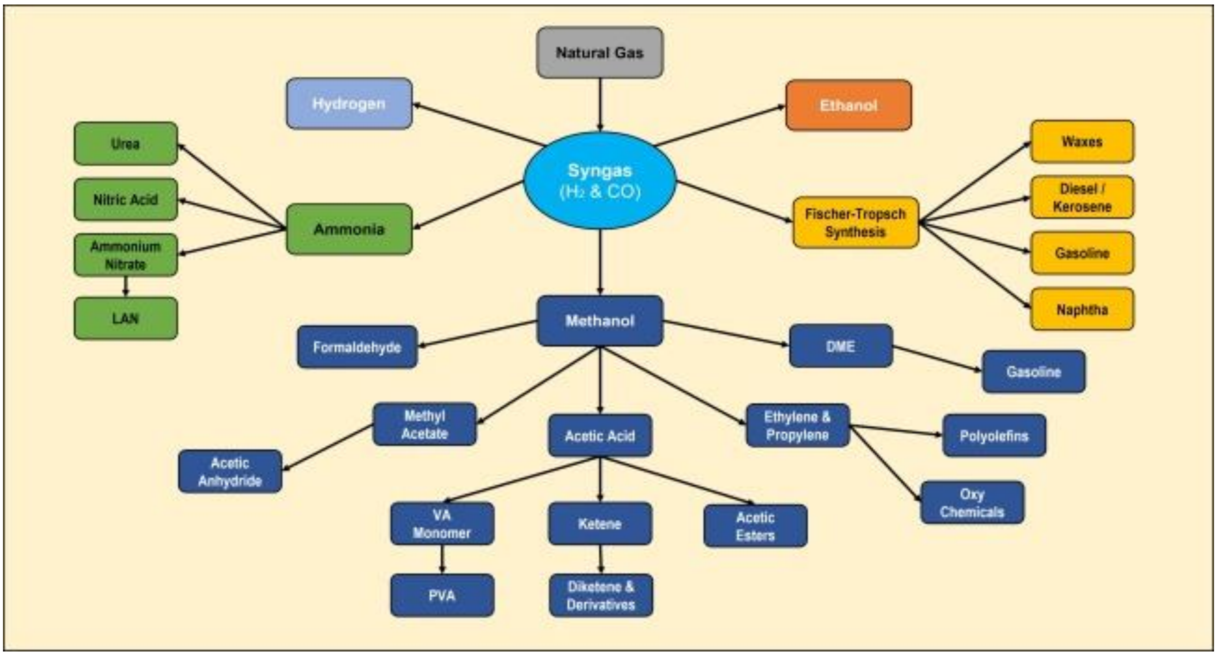

Figure 6: Chemicals from syngas obtained from NG

Other energy applications

'Other energy applications' is a catch-all for NG applications not discussed elsewhere…

NG is an excellent clean-burning fuel for boilers and incinerators. Industrial boilers are used to generate steam for many different applications in laundries, bakeries, breweries, dairies, hospitals, paper producers, food industries, wood processing, chemical industries, and others. Boilers due for replacement, can be replaced with NG-fired boilers at a lower cost than comparable oil- or coal-fired boilers. Alternatively, oil-fired boilers can be converted to run on NG.

Incineration is a waste treatment process, typically oil-fired, that involves the combustion of substances contained in waste materials. Incinerators can easily be converted to use NG as fuel source. Incineration can be used for waste-to-energy facilities where heat is used to generate steam for electricity.

Closing Remarks

This article focuses on the many outlets, opportunities, and applications of NG. The important next step in South Africa is to grow the demand for NG by making more gas available in the local market at an attractive price. Apart from only looking at imported NG, either by pipeline from Mozambique or by ship as LNG, local NG sources should also be considered. This means fast-tracking the development of the shale gas resources in the Karoo, and relooking at coal-bed methane resources.

The role of coal in South African industry and power generation is already decreasing, while that of gas and renewables is increasing. This trend will continue due to high greenhouse gas emissions associated with coal and the consequent inability to attract finance for coal-based projects. According to the Boston Consulting Group (2020), there is a vast array of gas technologies, and their deployment has the potential to economically reduce up to one third of emissions from the energy sector by 2040.

Government support is essential to substantially grow the role that NG plays in the South African energy mix, but this is not always forthcoming. Appropriate government policy is vital to ensure that the value of reduced greenhouse gas emissions brought about by NG use is fairly reflected in the market. This can be achieved by regulation, incentives, or carbon taxation.

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