*Orbital: Electron. J. Chem.* **2024**, 16(3), 169-175

the electronic journal of **chemistry**

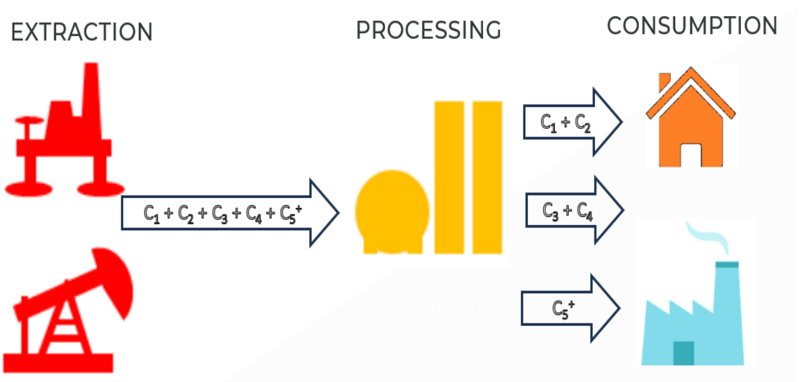
**Full Paper** | http://dx.doi.org/10.17807/orbital.v16i3.19859

# Alternatives for the Processing of Natural Gas in Espírito Santo

Kelen Carolina Altenerath* [a], Valdemar Lacerda Junior [a], and Claudio Penedo Madureira [b]

**Natural gas has shown an increase in demand in recent years, largely due to its competitive advantages over other fossil fuels. However, in Brazil, its production and supply chain remain under the monopoly of Petrobras, which makes it difficult for new agents to enter the market and often causes other producers to dispose of their production without any financial return. Therefore, the objective of this work is to identify alternative technologies for natural gas processing, to allow other natural gas producing companies to commercialize their natural gas production without depending on Petrobras' infrastructure. As a result, three technologies were identified that are already being applied in other countries, which are: compressed natural gas, liquefied natural gas and gas-to-liquids.**

## Graphical abstract




Keywords

Chemical processes
Espírito Santo
Natural gas
Technological alternatives

Article history

**Received** 11 Dec 2023
**Revised** 03 Jul 2024
**Accepted** 29 Jul 2024
**Available online** 08 Oct 2024

**Handling Editor:** Adilson Beatriz

## 1. Introduction

Natural gas, as the petroleum, is a fossil resources resulting from the degradation of organic matter, being found in underground reservoirs, whether onshore or offshore. It can be extracted from oil reservoirs (associated with oil) or natural gas reservoirs [1]. To refer to natural gas in its original form, as found in nature, the term 'wet natural gas' is adopted, and is defined as "any hydrocarbon that remains in a gaseous state under normal atmospheric conditions, extracted directly from petroleum or gasifers reservoirs, including wet, dry, residual and rare gasses" [1].

The composition of this gas is a variable that depends on the organic matter that gave rise to it and the natural processes to which it was subjected. These factors also influence the final composition of the gas for consumption, which is called dry natural gas [2]. It is essentially composed of methane (CH4) and ethane (C2H6), also containing small fractions of propane (C3H8), butane (C4H10) and even heavier fractions (C5+) and some contaminating gases such as oxygen, carbon dioxide, sulfur and hydrogen sulfide gas [1].

The composition of dry natural gas, which is the gas commercialized to attend industrial and residential purposes, is established by the Brazilian National Agency for Petroleum,

[a] Chemistry Postgraduate Program, Federal University of Espírito Santo, 29075-910, Vitória-ES, Brazil. [b] Law Postgraduate Program, Federal University of Espírito Santo, 29075-910, Vitória-ES, Brazil. *Corresponding author. E-mail: **kelen.altenerath@gmail.com**

Natural Gas and Biofuels (ANP) in its Resolution 16/2008, with methane as the main current component. The gas specification considers conditions like calorific value and Wobbe Index and define limits of hydrocarbons and contaminants [3].

Despite not being a renewable fuel, natural gas is considered a less polluting source than oil and its derivatives and is included by experts in the group of so-called Clean Energies [4]. For this reason, with the advent of discussions on climate change and the need for a transition in the global energy matrix, natural gas is no longer a by-product of oil production and is now seen as a fuel of high value and importance for this period of energy transition [5], being responsible for about 23% of the world's energy matrix [6]. Brazil is not out of this context, where the presence of natural gas has grown in importance in the national energy matrix, about 8% [6], especially because it presents itself as an alternative for the generation of electric energy (in times of water crisis) and as a source of energy for industries.

As with the petroleum chain, the specialized literature usually divides the natural gas chain into three segments: (i) *upstream*, (ii) *midstream* e (iii) *downstream*. Upstream encompasses the operations of research, exploration, extraction and flow of wet natural gas to a processing unit, better known as the E&P segment. The midstream, however, involves the industrialization or processing of wet gas (raw product), producing derivatives that can be consumed by the market. Downstream, on the other hand, includes all the logistics of transportation and distribution of the products generated in the processing to the final consumers [7].

Thus, the natural gas chain begins with its extraction from reservoirs, whether onshore or offshore. After that, the gas stream needs to be subjected to a minimum (or primary) conditioning to separate the water and oil streams and remove part of the contaminants present [8]. Once this primary conditioning is done, which takes place in the exploration and production (E&P) segment, the natural gas can be used mainly for three purposes: (i) use in the production plant itself, for energy generation and operational security, (ii) reinjection, for storage or production stimulus, these still located in the E&P segment (upstream) and (iii) flow to the processing units (UPGNs), which are located in the processing segment (midstream) [1], from which two main derivatives arise - dry natural gas and liquefied natural gas -, responsible, together with liquefied petroleum gas (a derivative obtained from crude oil in refineries), for meeting the consumption demand of industries and households.

There is, however, a singularity that marks the natural gas chain in Brazil, which is the presence of a single market agent in the natural gas processing segment. In fact, in Brazil, both the E&P segment and the natural gas processing segment are characterized by the historical presence of a dominant agent, currently responsible for 87,4% of all oil and natural gas production in the country [9] and owner of practically all natural gas flow and processing infrastructure [10]. This fact has forced the new entrants in the oil and natural gas exploration and production (E&P) segment to look for alternatives to insert their production in the market [11].

The dominance of a single market agent over the national oil and natural gas chain is mainly due to two factors. The first factor is that this dominant agent has already exercised a monopoly over the economic activities developed in all segments of the Brazilian oil and natural gas industry for a period of 44 years, from 1953 (institution of the monopoly by Federal Law n° 2.004 [12]) to 1997 (when Federal Law n° 9.478 was published [13], to regulate Constitutional Amendment n° 9/1995 which provides for the breaking of the monopoly). The other factor is that, even with the breaking of the legal monopoly in 1997, it took a long time for new agents to enter the Brazilian market, and when this happened, their focus (of these new agents) was focused only on the E&P segment [11]. Thus, in the absence of new investments in the processing/refining segment by the new players that entered the industry after the monopoly was broken, the production plants (UPGNs, refineries, regasification terminals) and the transportation infrastructure (pipelines), especially with regard to the production/transportation of natural gas, remained in the hands of a single market agent [14].

However, it has been observed in recent years that, after actions by the Federal Government (with emphasis on the Gas to Grown (*Gás para Crescer*) Initiative [15] the New Gas Market (*Novo Mercado do Gás*) Program [12]) and State Governments [16] (with the enactment of state laws on the new market system), new gas suppliers have entered the natural gas market, a fact that authorizes us to affirm that the first step was taken, even if in a timid way.

When entering the market, these new suppliers are faced with two situations, which are: a) either they use the existing infrastructure belonging to the dominant agent, through access to basic infrastructures [17] (gas pipelines, UPGNs and regasification terminals), the result of an extensive regulatory and tax effort, either for internal processing or for the import of natural gas (liquefied natural gas – LNG); b) or explore other technical solutions to specify the wet natural gas produced in the country as a way to make it viable to market it as a substitute for the dry gas processed.

For this reason, this article intends to describe alternatives for the processing and, consequently, for the commercialization of natural gas by those companies that have natural gas production, but do not have the processing infrastructure of a Natural Gas Processing Unit (UPGN), in order to allow the market to become accessible to more agents and, thus, enable the expansion of the supply of marketable gas in the country. More specifically, the article plans to focus on the natural gas chain located in the State of Espírito Santo, pointing out, based on the currently existing structure (onshore and offshore production, agents currently existing in the Espírito Santo market, consumption, etc.), how alternatives to the traditional economic chain model can foster the natural gas industry in this federated entity, creating new jobs and income for the local and national economy.

## 2. Material and Methods

This work used bibliographic and documentary research as a method, seeking information in primary and secondary sources. The development of the research began with the reading of bibliographies that allowed us to understand the history and current situation of the natural gas chain in Brazil, identifying the way the industry started and is currently structured, as well as what are its expectations for the short and medium term.

To map the natural gas chain, as well as the productive areas of the State of Espírito Santo, the statistical data and information made available in the reports and studies developed by the National Agency of Petroleum, Natural Gas and Biofuels (ANP in its Portuguese acronym), Ministry of Mines and Energy (MME) and the Energy Research Company (EPE in its Portuguese acronym) were used.

The next step was to find out information about how natural gas is currently processed and marketed in Brazil, and how the market is arranged, from national publications.

To conclude the research, a survey of the available technologies or under study was carried out, and that could be used as an alternative to the current model. Such information was collected in articles and studies published nationally and internationally, especially by institutes and research agencies in the energy sector.

## 3. Results and Discussion

### 3.1 Oil and natural gas production area in Espírito Santo

The State of Espírito Santo has two sedimentary basins with exploration and production of oil and natural gas: the Espírito Santo Basin, which is found in both the onshore and offshore environments (north coast), and the Campos Basin (Bacia de Campos), which is in the southern coastal part (offshore environment) and extends through the State of Rio de Janeiro [18].

The Espírito Santo sedimentary basin has a total exploitable area of 41.500 $km^2$, of which 3.000 $km^2$ are onshore, located in the northern region of the state [19]. The Campos Basin (Bacia de Campos), on the other hand, has an exploitable area of 100.000 $km^2$ in an exclusively offshore environment [20].

According to a report published by the ANP in June 2024, the State of Espírito Santo has 39 fields in the production phase (excluding those in the return phase), of which 26 are onshore [18].

Most of these fields were originally granted to Petrobras [21]. However, the company has been going through a divestment process since 2015 [22]. This led to the entry of new operators in the exploration and production segment, especially in onshore fields [23]. In June 2024, in addition to Petrobras, there were 11 other concessionaires operating in the state, of which 8 operate exclusively in the onshore environment [18]. There is also the expectation that more fields, both onshore and offshore, are taken over by small and medium-sized companies in the short term, either through the purchase of Petrobras' assets or through the acquisition of rights from the ANP in the bidding rounds promoted by the agency, in line with the guidelines of The National Energy Policy Council (CNPE). Some of these companies are specialized in mature fields and fluid recovery techniques, which generates the expectation of investments in the sector and consequent increase in production rates [24], and projects the need for a market for the commercialization of this production.

Based on ANP data, the fields in the production phase that are not operated by Petrobras (the only company that has natural gas processing infrastructure in Espírito Santo) [18] were identified, as well as the chromatography of each producing fields [25] and the average production in the period from January 2023 to April 2024 [26]. Due to the operating conditions, it is normal for fields belonging to the same operator and that are in nearby production areas to have their production added up. Thus, arrangements were constructed per operator and per production environment, as demonstrated in Table 1.

### 3.2 Conventional natural gas processing in Espírito Santo

The main destination given to natural gas in Brazil is still sent to a UPGN, where the gas is subjected to thermodynamic processes to fractionate and obtain the by-products to be marketed [27].

The fractionation of natural gas aims to adapt its by-products to the commercialization specifications defined by the ANP and to obtain the highest possible added value with its commercialization [27]. Thus, the raw natural gas (or wet) is processed in the UPGNs, to separate the hydrocarbon fractions and, finally, to obtain, as by-products, dry natural gas and natural gas liquids (GLGN and natural gasoline – $C^{5+}$).

The choice of the fractionation process to be applied depends on a technical and economic analysis, which will depend, on a case-by-case basis, on the specificities of the raw natural gas to be processed and the desired by-products [28]. Thus, each UPGN is modeled with specific characteristics, so that, in addition to the fractionation process, they can employ auxiliary systems [28].

In general, the processing of raw natural gas consists of a liquefaction stage (which involves the condensation of the heavier fractions), a fractionation stage (which involves the separation of the gas and liquid streams) and, finally, a by-product specification stage [28]. The difference between the processes is the mechanism adopted in each of the stages and the expected efficiency in the recovery of each hydrocarbon fraction [28].

The thermodynamic processes currently adopted in Brazilian UPGNs are of four types: (i) Joule-Thomson expansion, (ii) refrigeration process, (iii) gas-liquid absorption and (iv) the turbo-expander process [28].

The Joule-Thompson expansion process is declared to be the simplest technology and is based on cooling the gas through an isenthalpic expansion. The incoming natural gas is pre-cooled in a gas/gas exchanger, passes through the isenthalpic valve, where the pressure variation occurs, and consequently, temperature reduction, to achieve phase equilibrium. Then, in a separator vessel, the division between the liquid and gaseous phases occurs [29].

The refrigeration process also works based on reducing the temperature of the gas to separate the phases, reaching the dewpoint of the gas. In this, however, the system reduces the temperature by thermal exchange between natural gas and a fluid refrigerant, usually a propane refrigeration cycle, which is one of the by-products of processing [1].

The gas-liquid absorption technology has as a mechanism the washing of the gas in countercurrent to a liquid phase. It is an exothermic process, with the exchange of mass from the heavier fractions present in the raw natural gas, when inserted in the absorber column, to the liquid phase passed in countercurrent in the column, due to the thermodynamic equilibrium achieved under specific conditions of pressure and temperature. The efficiency of this system is a ratio between the temperature of the inlet gas, the pressure of the absorber column, and the flow rate of the absorption oil [1].

The gas collected at the top of the column is already specified for injection into the transport pipelines, while the liquid stream recovered at the bottom of the column must undergo regeneration treatment before returning to the absorber column, removing the ethane and propane from the process [27]. The absorption oil used in the process needs to have high gas solubility, be non-toxic, stable and have low volatility, and for this reason, turpentine is usually used [28].

Finally, there is the turbo-expander process, which is the most traditional when seeking the best efficiency in the recovery of the natural gas liquid [29]. It is a more complex process, where initially the charge gas passes through gas/gas exchangers, in an external cooling system with closed cycles. After that, this chilled gas is separated in a cold separator (reaching up to cryogenic temperatures) into the liquid and gaseous fractions [27]. After that, the gaseous fraction is subjected to a turbo-expander, in which, in an isentropic expansion, it reaches low temperatures and liquefies the fraction of ethane that remains in the gas stream, recovering as much as possible from the heavy fractions [28].

**Table 1.** Productive arrangements of oil and natural gas fields located in the State of Espírito Santo due to the operator and production environment [25, 26].

| FIELD | CHROMATOGRAPHY (%) | | | | | | Daily Average Production |
|---|---|---|---|---|---|---|---|
| | $CH_4$ | $C_2H_6$ | $C_3H_8$ | $C_4H_{10}$ | $C_5^+$ | contaminants | $m^3\,d^{-1}$ (Jan/2023 - Apr/2024) |
| CANGOÁ | 0.92090 | 0.02330 | 0.0115 | 0.0069 | 0.0059 | 0.03150 | 47,027 |
| PEROÁ | 0.92260 | 0.02260 | 0.0104 | 0.0069 | 0.006 | 0.03150 | 476,079 |
| **ARRANGEMENT 3R - OFFSHORE** | **0.92245** | **0.02266** | **0.01050** | **0.00690** | **0.00599** | **0.03150** | **523,106** |
| CAMARUPIM | 0.86030 | 0.06100 | 0.02780 | 0.01360 | 0.01210 | 0.02520 | - |
| CAMARUPIM NORTE | 0.86030 | 0.06100 | 0.02780 | 0.01360 | 0.01210 | 0.02520 | - |
| CANAPU | 0.83015 | 0.06543 | 0.04048 | 0.02716 | 0.02209 | 0.01469 | - |
| GOLFINHO | 0.88430 | 0.07460 | 0.00550 | 0.01560 | 0.00390 | 0.01610 | 100,915 |
| **ARRANGEMENT BW - OFFSHORE** | **0.88430** | **0.07460** | **0.00550** | **0.01560** | **0.00390** | **0.01610** | **100,915** |
| ABALONE | 0.84488 | 0.08959 | 0.03446 | 0.01422 | 0.00574 | 0.01111 | 179,285 |
| ARGONAUTA | 0.84883 | 0.04243 | 0.01329 | 0.01246 | 0.01218 | 0.07081 | 225,537 |
| OSTRA | 0.71213 | 0.17553 | 0.05541 | 0.02080 | 0.01374 | 0.02239 | 41,433 |
| **ARRANGEMENT SHELL - OFFSHORE** | **0.83455** | **0.07373** | **0.02571** | **0.01394** | **0.00974** | **0.04233** | **446,255** |
| ÁGUIA REAL | | | undisclosed chromatography | | | | - |
| LAGOA PARDA | 0.84693 | 0.04579 | 0.03234 | 0.02136 | 0.03145 | 0.02213 | 8,196 |
| LAGOA PARDA NORTE | 0.91200 | 0.04060 | 0.00410 | 0.00350 | 0.01060 | 0.02920 | 920 |
| RIO IPIRANGA | 0.84437 | 0.06556 | 0.03944 | 0.02168 | 0.02116 | 0.00779 | 4,006 |
| **ARRANGEMENT CAPIXABA/IMETAME - ONSHORE** | **0.85071** | **0.05146** | **0.03253** | **0.02021** | **0.02685** | **0.01825** | **13,122** |
| CACIMBAS | 0.92060 | 0.03150 | 0.01190 | 0.00560 | 0.00500 | 0.02540 | 298 |
| CAMPO GRANDE | 0.85340 | 0.05410 | 0.03530 | 0.02120 | 0.01760 | 0.01840 | 203 |
| CANCÃ | 0.96780 | 0.01740 | 0.00100 | 0.00070 | 0.00050 | 0.01260 | 2,338 |
| CÓRREGO DOURADO | 0.92000 | 0.02820 | 0.01380 | 0.01160 | 0.00780 | 0.01860 | 60 |
| FAZENDA ALEGRE | 0.97851 | 0.00536 | 0.00067 | 0.00033 | 0.00128 | 0.01385 | 16,605 |
| FAZENDA CEDRO | 0.84582 | 0.00645 | 0.03715 | 0.02115 | 0.01704 | 0.07239 | 469 |
| FAZENDA SANTA LUZIA | 0.90120 | 0.05100 | 0.02260 | 0.01140 | 0.00790 | 0.00590 | 14,350 |
| FAZENDA SÃO JORGE | 0.91923 | 0.02729 | 0.01488 | 0.01332 | 0.00958 | 0.01570 | 938 |
| FAZENDA SÃO RAFAEL | 0.82930 | 0.08100 | 0.04680 | 0.02360 | 0.01380 | 0.00550 | 9,688 |
| INHAMBU | 0.91100 | 0.00510 | 0.00540 | 0.00270 | 0.00180 | 0.07400 | 640 |
| LAGOA SURUACA | 0.78629 | 0.09068 | 0.06297 | 0.02634 | 0.00741 | 0.02631 | 431 |
| RIO ITAÚNAS | 0.87880 | 0.04420 | 0.01410 | 0.00650 | 0.00390 | 0.05250 | 189 |
| SÃO MATEUS LESTE | 0.88200 | 0.04610 | 0.03000 | 0.01160 | 0.01050 | 0.01980 | 78,879 |
| TABUIAIÁ | 0.90070 | 0.00530 | 0.00140 | 0.00080 | 0.00030 | 0.09150 | 700 |
| JACUTINGA | | | undisclosed chromatography | | | | 1,139 |
| **ARRANGEMENT SEACREST - ONSHORE** | **0.89459** | **0.04283** | **0.02572** | **0.01080** | **0.00895** | **0.01712** | **126,927** |
| BEM-TE-VI (VIPETRO) | | | undisclosed chromatography | | | | 0 |
| CREJOÁ (TARMAR) | | | undisclosed chromatography | | | | 0 |
| IRARA (BGM) | | | undisclosed chromatography | | | | 200 |
| MURIQUI (BGM) | | | undisclosed chromatography | | | | 10 |
| RIO MARIRICU (MANDACARU) | 0.89090 | 0.04890 | 0.02390 | 0.01135 | 0.00116 | 0.02379 | 70 |
| SUINDARA (BGM) | | | undisclosed chromatography | | | | 40 |
| TUCANO (VIPETRO) | | | undisclosed chromatography | | | | 30 |

### 3.3 Alternatives to the use of gas in Espírito Santo

As already explained, the breaking of the legal monopoly of natural gas production happened in 1997, however, it took years for new actors to have active participation in national production. And when they began to participate, they encountered barriers about the flow and commercialization of their production, especially natural gas [14].

International studies indicate that the search for alternatives to conventional natural gas processing is not a particularity of Brazil. It is true that this occurs in Brazil and in the rest of the world for different reasons. While in Brazil its purpose is to try to escape the monopoly exercised by a dominant agent, in other countries this strategy has its origin in structural problems, such as the lack of flow infrastructure, the great distance from the consumer market, or even the fact that local production is too low for the implementation of robust processing plants [30].

In the production scenario of Espírito Santo, there are 12 operators with oil and gas production, among them Petrobras [18]. Among them, only Petrobras owns and operates the processing units installed in the state [10]. Thus, the other operators need to sell their gas to it, send it to industrialization or look for a new alternative for conditioning [14].

Seen in these terms, this article seeks to identify, and describe, in view of the specificities of the productive environment in Espírito Santo, the alternatives available in the field of chemistry, so that new actors make use of the natural gas produced in the State, forming new productive arrangements. In addition, it was chosen, as a methodological cut, to limit the research to technologies in which the final product continues to be natural gas, or that is linked to its production process.

The two main alternatives adopted around the world to increase the availability of gas to the consumer market are (i) the compression of natural gas by compressed natural gas (CNG) technology and (ii) the liquefaction of natural gas for transportation and commercialization by liquefied natural gas (LNG) technology [31]. There are also records of the use of processes to convert the gas into other hydrocarbon streams, as seen in gas-to-liquids (GTL), in which the final product can be mixed and marketed together with crude oil [31].

In the following topics, these alternatives will be detailed by explaining their application conditions and what is involved in each production process.

*Compressed natural gas*

Compressed natural gas (CNG) technology consists of compressing natural gas, reducing its volume by about 150 to 300 times when compared to atmospheric pressure conditions, and transporting it under this condition [31]. The subjection of the gas to these compression ratios causes the heavier fractions present in the gas stream to be condensed and thus separated [1].

Its use takes place when it is desired to consider serving consumers close to the region of production and with lower demand [31].

The CNG chain involves four steps: (i) Gas treatment, (ii) Compression, (iii) Transport e (iv) Delivery, as shown in Fig. 1. Each stage is dependent on the conditions of the wet natural gas produced and the characteristics required for delivery to the final consumer.

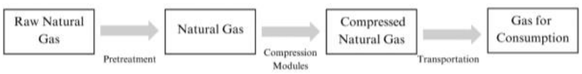



**Fig. 1.** Schematization of compressed natural gas technology [31].

The process of gas compression consists of subjecting the gas to high pressures, raising its temperature due to the performance of work, and leaving it in the condition of superheated steam. Subsequently, that vapor will be exposed to a cooler to control the temperature, causing the heavier fractions present in the gas to condense and allow separation in a vertical gas scrubber [1].

The compression module consists of a system of compressors in series, in which the compression will occur in successive stages until the required compression ratio is reached. The cited ratio is determined from the dew point curve of each gas stream to be processed [1,30].

*Liquefied natural gas (LNG)*

Liquefied natural gas (LNG) technology is conventionally adopted for transporting large volumes of gas over long distances, as liquefaction allows to increase the energy density of the gas by up to 600 times when compared to atmospheric conditions of pressure and temperature [31].

It is a technology that has been applied for many decades. The first plant was installed in the 1960s in the United Kingdom [31]. Historically, it is also an applied technology using piped gas as a feed gas. That is, the gas went through processing in a UPGN and was specified for transportation in pipelines [32].

However, this technology has already been applied to associated natural gas [32]. Plants are built with less capacity to discharge the production carried out in producing areas without outflow infrastructure or to serve consumer markets that are far from the producing area and have no connection with the distribution network [31].

The LNG applied to natural gas extracted directly from reservoirs involves pre-treatment processes, liquefaction modules, transportation and regasification stations at gas delivery points. Fig. 2 shows the main steps of the technology.

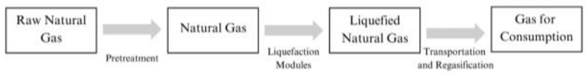



**Fig. 2.** Schematization of liquefied natural gas technology [31].

As with compressed natural gas technology, pretreatment may be necessary depending on the composition of the gas, to remove the heaviest fractions of hydrocarbons, contaminants and water [31]. The minimum conditions required for the inlet gas are: (i) Water/$H_2O$ – 0.1 ppmv; (ii) Carbon dioxide: 50 ppmv; and (iii) hydrogen Sulfide: 4 ppmv [32].

In the liquefaction modules, the feed gas (post-treated and conditioned) is subjected to a refrigeration cycle with temperatures ranging from -145 ºC to -160 ºC. Refrigerant cycles can be closed or open, single or multiple, with one refrigerant or more [32].

There are many liquefaction techniques developed and licensed for the liquefaction of natural gas, however, for small-scale application, three stand out: nitrogen expansion cycle, gas expansion and mixed refrigerant [31]. But in a simple way, a liquefaction unit will basically consist of heat exchangers, a refrigerant gas and a turbine.

The definition of the best technique occurs largely due to the availability of equipment for the construction of the plants and the need for the temperatures required to obtain the specification of the gas for commercialization.

*Gas-to-liquids*

The *gas-to-liquids* (GTL) alternative promotes the conversion of natural gas into liquid fuels and(or) petrochemicals. It is an old process, with the first plants built between 1926 and 1944 in Germany, but it has been remodeled to meet the conditions of lower volume production [31].

Initially, it is necessary for the natural gas to be free of contaminants and heavier fractions to adjust the dew point. In other words, some of the pre-treatment processes already mentioned in the work should be applied [31].

Then, this incoming natural gas will be converted into syngas, A mix of CO and $H_2$, through steam reforming of methane or autothermal reforming [33].

The syngas undergoes a Fischer-Tropsch reaction, giving rise to a synthetic crude oil (syncrude) – a mixture of waxes, middle distillates and naphtha. The syncrude formed can be mixed with the crude oil produced in the fields, ending the GTL process, or it can be subjected to another step and be converted into liquid fuels and/or petrochemicals [31], as shown in Fig. 3.

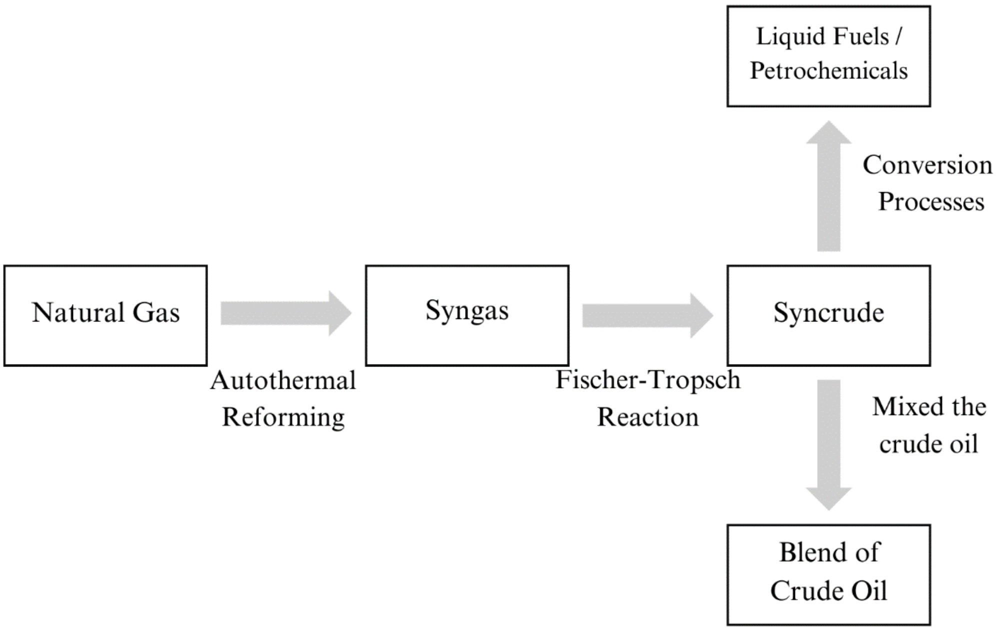



**Fig. 3.** Schematization of the processes involved in gas-to-liquids technology [33].

Studies have been carried out in order to optimize the GTL process, both in terms of flexibility of the volume processed and with regard to the processes and equipment involved, such as application of gliding arc plasma gas reforming and use of partial oxidation reactors in the transformation of syngas, and, the development of new Fischer-Tropsch microchannel reactors in the syncrude formation stage [31].

## 4. Conclusions

Three possible alternatives for the processing of natural gas and its subsequent commercialization were found within the proposed methodological cut, all of which are already being used in productive areas around the world.

Compressed natural gas (CNG) and liquefied natural gas (LNG) technologies are well-known technologies. However, its use usually takes place on a large scale, and presupposes the use of processed gas. However, the use of small-scale plants has proven to be feasible in other areas of the world, allowing the gas to remain in the necessary conditions for commercialization with industries.

In the case of Espírito Santo, the wet gas arrangements analyzed, with exceptions to the SHELL arrangement, have a chemical composition with the major fractions of methane and ethane, facilitating the specification determined by ANP regulations when using the aforementioned technologies.

The third technology, gas-to-liquids (GTL), does not generate natural gas as a product for sale to the market, but promotes its conversion into a synthetic oil, liquid fuel or petrochemical products. As a result, there is no expansion of the supply of natural gas to the consumer market and no diversification of agents in the gas supply chain. Even so, GTL technology may present itself as a good alternative for the productive arrangements of the State, since the product generated can be mixed with crude oil, which has a certain market for the producing companies.

Thus, the three technologies mentioned are viable and possible to apply with regard to operational and regulatory issues. However, it is not possible to determine the best choice for each production area, because it would be necessary to deepen the processes involved in each technology, in addition to deepening the characteristics of each production area, with the performance of process simulations for each natural gas stream, as each technology allows different arrangements of equipment and processes.

## Author Contributions

KCA – conceptualization, methodology, investigation, data curation, writing – original drafting, writing – review & editing, visualization. VLJ – conceptualization, validation, writing – review, supervision. CPM – conceptualization, methodology, validation, writing – review, supervision.

## References and Notes

[1] Vaz, C. E. M.; Maia, J. L. P.; Santos, W. G. dos. In: Tecnologia da Indústria do Gás Natural, ed. São Paulo: Blucher, 2008.

[2] Fioreze, M. et al. Management, Education and Environmental Technology Journal, 2013, 10, 2251. [https://periodicos.ufsm.br/reget/article/view/7896/pdf]

[3] Brazilian National Agency for Petroleum, Natural Gas and Biofuels. Resolution nº 16, of June 18, 2008.

[4] Available from: https://veja.abril.com.br/mundo/uniao-europeia-diz-que-gas-natural-e-energia-nuclear-sao-energias-verdes. Access June 2024.

[5] Yergin, D. In: A Busca: energia, segurança e reconstrução do mundo moderno, ed. Rio de Janeiro:

Intríseca, 2014.

[6] Available from: https://www.energyinst.org/statistical-review. Access June 2024.

[7] Fernandes, E.; Araújo, R.S.B. de. Abstract of the XXIII Congresso Nacional de Engenharia de Produção, Ouro Preto, Brasil, 2003.

[8] Anna, A. A. S.; Medeiros, J. L.; Araújo, O. Q. F. Abstract of the do 3º Congresso Brasileiro de P&D em Petróleo e Gás, Salvador, Brasil, 2005.

[9] Available from: https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/boletins-anp/boletins/boletim-mensal-da-producao-de-petroleo-e-gas-natural. Access June 2024.

[10] Available from: https://www.gov.br/anp/pt-br/centrais-de-conteudo/publicacoes/anuario-estatistico/anuario-estatistico-brasileiro-do-petroleo-gas-natural-e-biocombustiveis-2024 . Access June 2024.

[11] Available from: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-crescer/consulta-publica/1.GsparaCrescer_Comercializacao.pdf. Access June 2024.

[12] Brazil. Law nº 2.004, of October 03, 1953.

[13] Brazil. Law nº 9.478, of August 06, 1997.

[14] Available from: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/novo-mercado-de-gas. Access June 2024.

[15] Available from: https://www.gov.br/mme/pt-br/assuntos/secretarias/petroleo-gas-natural-e-biocombustiveis/gas-para-crescer/gas-para-crescer-1. Access June 2024.

[16] Available from: https://abrace.org.br/conteudos-tecnicos/ranking-do-mercado-livre-de-gas-relivre/. Access June 2024.

[17] Brazil. Law nº 14.134, of April 08, 2021.

[18] Available from: https://www.gov.br/anp/pt-br/centrais-de-conteudo/paineis-dinamicos-da-anp/paineis-dinamicos-sobre-exploracao-e-producao-de-petroleo-e-gas/paineis-dinamicos-de-producao-de-petroleo-e-gas-natural. Access June 2024.

[19] Available from: https://www.researchgate.net/publication/273336978_Bacia_de_Espirito_Santo_Boletim_de_Geociencias_da_Petrobras. Access June 2024.

[20] Poubel, R.; Junior, P. J. S. Abstract of the Anais do XVI Seminário de Integração UCAM: do global ao local – o poder das escalas sobre o território, Campos de Goytacazes, Brasil, 2017.

[21] Available from: https://www.gov.br/anp/pt-br/rodadas-anp/rodadas-concluidas/rodada-zero. Access June 2024.

[22] Available from: https://bipbrasil.com.br/desinvestimentos-petrobras/. Access June 2024.

[23] Available from: https://portal.fgv.br/artigos/companhias-independentes-desinvestimentos-petrobras-brasil-e-sociedade-relacao-ganha-ganha. Access June 2024.

[24] Available from: https://findes.com.br/news/venda-de-concessoes-do-polo-cricare-no-norte-do-es-findes-destaca-importancia-para-a-economia-estadual/. Access June 2024.

[25] Available from: https://www.gov.br/anp/pt-br/assuntos/royalties-e-outras-participacoes/preco-de-referencia-do-gas-natural . Access June 2024.

[26] Available from: https://www.gov.br/anp/pt-br/assuntos/royalties-e-outras-participacoes/*royalties*. Access June 2024.

[27] Quaranta, I. C. C. Dimensionamento de uma coluna de absorção para processamento de gás natural. [Master's thesis.] Fortaleza, Brasil: Universidade Federal do Ceará, 2021. [http://repositorio.ufc.br/handle/riufc/57758]

[28] Available from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-457/Considera%C3%A7%C3%B5es%20sobre%20a%20Participa%C3%A7%C3%A3o%20do%20G%C3%A1s%20Natural%20na%20%20Matriz%20Energ%C3%A9tica%20no%20Longo%20Prazo.pdf. Access June 2024.

[29] Cordeiro, A. F. Estudo de simulação e controle de uma unidade de processamento de gás natural. [Master's thesis.] Rio de Janeiro, Brasil: Universidade Federal do Rio de Janeiro, 2011. [http://epqb.eq.ufrj.br/wp-content/uploads/2021/04/11_21.pdf]

[30] Available from: https://documents1.worldbank.org/curated/en/210571472125529218/pdf/104200-V2-WP-CNG-commercialization-PUBLIC-Main-report-REPLACEMENT.pdf. Access June 2024.

[31] Available from: https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-487/EPE,%202020%20-%20NT%20Monetiza%C3%A7%C3%A3o%20de%20GN%20onshore%20-%20Rev1.pdf. Access June 2024.

[32] Available from: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/299861484716073109/executive-summary. Access June 2024.

[33] Available from: http://www.gasprocessingnews.com/features/201310/smaller-scale-gtl-enters-the-mainstream.aspx. Access June 2024.

## How to cite this article

Altenerath, K. C.; Lacerda-Junior, V.; Madureira, C. P. *Orbital: Electron. J. Chem.* **2024**, *16*, 169. DOI: http://dx.doi.org/10.17807/orbital.v16i3.19859