AN ANALYSIS OF THE IMPACTS OF THE PRODUCTION OF UNCONVENTIONAL GAS IN THE NORTH AMERICAN PETROCHEMICAL AND FERTILISER INDUSTRY

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1. Introduction

The petrochemical industry in the United States has gained a new impetus with the production of gas from unconventional sources, and, in special, from shale gas. Presently, the global outlook of the petrochemical industry is beginning to change, with a wave of enterprises which started to come up in regions of the world which were not traditionally large petrochemical producers, in particular in the Middle East and in Asia.

In the Middle East most of these new plants are gas-based. However, in this region, due to a relative scarcity of gas for new projects, it is expected by analysts that if further projects are announced they will not have access to low-cost ethane, with the exception of Qatar. Qatar, by its turn, has an ongoing moratorium in new gas projects involving North Field. In Asia most of the new projects are located in China, whose petrochemical production is mainly naphtha-based.

In this conjuncture the new petrochemical volumes arising from above mentioned wave of enterprises, even if there are not significant capacity additions further to these projects, could affect the industry in the United States, large petrochemical consumers as well as usual producers and exporters.

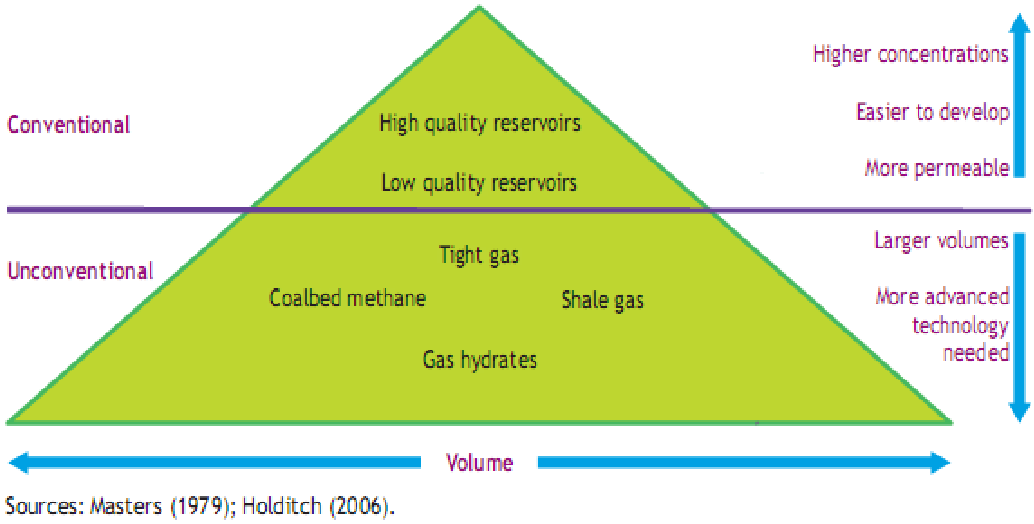
However, the petrochemical industry in the United States, which would face a fiercer competition environment with other producing countries with access to abundant and/or low cost feedstocks, has been able to reverse the trend of loss in competitiveness in the global scenario. With the growing unconventional gas production and a reduction in the natural gas prices levels in the country in relation to pre-2008 economic crisis levels, reaching mid-2000s values, there was a lengthening in the timeline in which the petrochemical industry in the United States remains competitive in the global market, what can be considered a long-term trend, backed by the fact that there are significant unconventional gas reserves. Thus, the impacts of the new petrochemical projects abroad in the segment were partially softened by the “new” advantage of feedstock access.

This work aims at analyzing how this true “revolution” of shale gas in the United States affected the local petrochemical industry, expanding their competitive horizons especially in reference to ethylene production. Energy consumption in the petrochemical industry occurs both as a raw material and as energy for fuel and power leading to relevant benefits when low energy prices are available. As a representative of the wide array of petrochemical molecules, the ethylene production in the country was chosen for analysis, as it is the petrochemical product with the largest world production volume and as it is used as an input for a large chain of derivatives, such as resins and solvents. For the fertilizer industry, it is briefly discussed the case of nitrogen fertilizers, considering the case of ammonia.

This study was carried out by means of analysis based on bibliographic research in specialized sources about U.S. energy markets, such as the Energy Information Administration of the U.S. Department of State as well as articles and presentations from specialized media, such as ICIS and CMAI.

2. Unconventional natural gas

Hydrocarbon deposits are generally classified in conventional and unconventional resources, as show in Figure 1.



Source: adapted from WEO, 2009

Figure 1: Types of natural gas resources and estimate of unconventional gas *in place* reserves.

There are different types of natural gas resources, each with distinct characteristics that require their own production techniques. The concept of a resources triangle illustrates how natural gas resources of all types are distributed according to size and ease of extraction (WEO, 2009). Next to the top of the triangle, representing a relatively small portion of the total resource basis, are the higher quality accumulations, generally conventional gas, which may be relatively easily and cheaply developed, and which also benefits from the fact that for being concentrated in a relatively small area, they can share infrastructure, thus reducing investments in midstream. Generally, conventional natural gas is the natural gas contained in sandstone or limestone with high porosity and permeability levels, allowing the gas to flow easily from the reservoir to the well. This set of characteristics allows these reservoirs to be developed with traditional vertical well technologies, with high recovery rates, which may surpass 80%.

The composition of unconventional gas does not differ from the conventional gas. Conventional as well as unconventional natural gas may have differences in their composition relating to the geological features particular to each producing region. What differs in both cases is the extraction technology (ACC, 2011; GÉNY, 2010; DOE/NETL, 2010; CRS, 2009; WEO, 2009).

Based on WEO (2009), the resources at the bottom of the triangle – mainly unconventional – are usually discovered in larger quantities, however, generally more difficulties are found in their production, requiring more complex technologies and/or high prices of energy sources so that they can be produced in an economically viable way. Unconventional gas usually spreads over large areas, but with lower recovery rates than conventional resources, currently in the range of an average of 20-30%. Unconventional gas is the term used for the gas contained in low permeability formations, typically spread over vast geographical areas, what makes this type of resource relatively easier to be discovered, although the production thereof is more complex or costly, this also being the case for midstream. However, in the United States, due to the growing efficiency in drilling and the advancement in the learning curve in each producing area, specially after the “sweet spots” have been identified, and due to the fact that these resources are typically onshore, the costs are being lowered, with the very cost structure being pressed by the success of the unconventional exploration, specially of shale gas, in the United States that led to lower prices of the natural gas in the markets.

Large discoveries of conventional gas are becoming scarcer, especially in mature exploration basins in Canada and in the United States. Further, the conventional production in the United States is declining and advances to more remote areas, such as Alaska and deepwaters, with higher costs.

As examples of types of unconventional gas there are:

- Coalbed methane (CBM): also called coal seam gas, it is found in most coal beds. The gas is mostly apprehended by the absorption in surfaces and inner part of the porous system of the organic components of the coal bed;
- Tight gas: it is trapped in low permeability formations, which reduce the free flow of gas to the producing wells. Nowadays, there is not a consensus about the definition of this type of gas. Tight gas was already able to be economically explored before the technological advancements that made the unconventional boom in the United States, but these new technologies had a positive impact on production levels. In some classifications, this type of gas is already represented together with conventional gas;
- Shale gas: it is predominantly contained in rocks (shales) rich in organic compounds and low grain size. It is housed in very low permeability formations and its production only became economically feasible with the new production techniques;
- Gas hydrates: crystalline compounds formed at low temperatures and at high pressures (WEO, 2009).

Unconventional resources begun to be more widely commercially explored by the application and adaptation of technologies which significantly increased the rock area in direct contact to the well and which, consequently, improved the gas flow to the well. The term unconventional is actually almost becoming an improper name for tight gas, coalbed methane and shale gas, due to the high volumes already produced and to the prospects for production growth, the word unconventional in a sense characterizing the need for employment of fracturing to enable or increase the economicity of the production. On the other hand, gas hydrates remain as a “truly unconventional” resource, in the sense that their commercial production is not very successful yet (WEO, 2009). Thus, the technological advances allowed the exploration of these said unconventional resources, in some cases even at lower costs than conventional production (IHS, 2011).

3. The evolution of unconventional gas exploration

The combination of a series of developments in hydraulic fracturing treatments and in horizontal well completion was essential to ramp up the expansion of shale gas production. Prior to the success in the application of these two technologies, the shale gas resources in many basins were neglected due to the fact that the production would not be economically attractive (ACC, 2011; IHS, 2011; DOE/NETL, 2010; CRS, 2009). The natural low permeability of the shale was considered as a limiting factor to the production, as it allowed the flowing of reduced volumes to the well. Historically, this restriction was regarded as little attractive to operators, which focused the production in conventional resources, with better outlooks for economic returns.

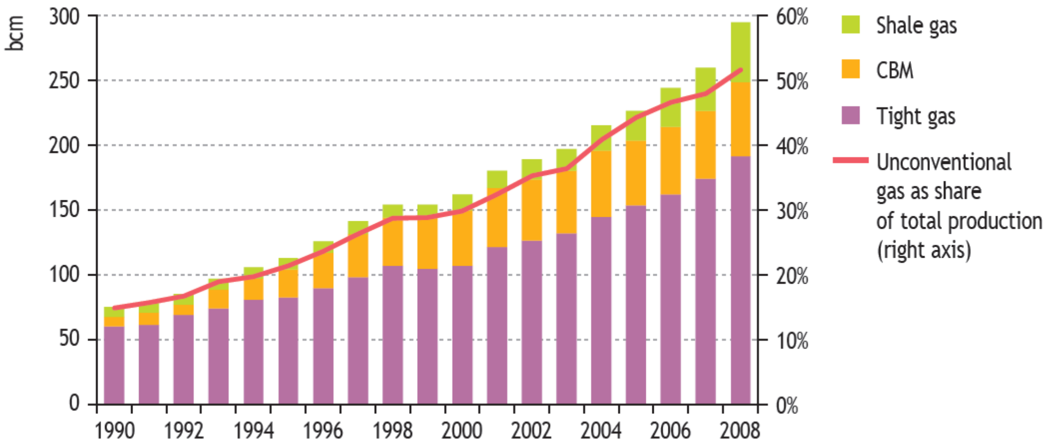
At the beginning, unconventional gas exploration took place at small scale in reduced but continuous volumes, through simple constructions, for household uses and for public illumination in some East Cost cities in the United States. The first actual producing well on the United States was completed in 1821, next to New York, where the gas was used for illumination. The first large scale shale gas development took place in Kentucky, in the 1920s (CRS, 2009).

In the United States, in the 1980s and 1990s, the growth of the unconventional gas production was stimulated by federal fiscal exemptions and by research developed by the U.S. Department of Energy (DoE) and by the Gas Research Institute (ACC, 2011; DOE/NETL, 2010). This supported the development of new technologies and provided economic support to the production during the years of gas prices at relatively low levels. Although the fiscal exemptions are no longer in force and the research programs have been reduced, these paved the way for the initial growth of the then small and at the time relatively few independent companies,

Later increases in natural gas price and the advancements in the production led to the commercial viability of unconventional resources. The depletion of conventional reserves also contributed to the growth of the production of this type of gas, once the alternative to ensure supply would be resorting to the growth of imported volumes from Canada at relatively low prices, what was being exhausted, and the new alternative would be LNG imports, at higher costs that would compete with the flows of LNG from the Middle East and other producing countries to Asia and Europe, with prices usually fixed by the energy parity to oil.

In the period from 2000 to 2007, the drilling activity on shale gas in North America increased more than 10-fold, with a high increase in the number of companies within this activity (WEO, 2009). The success in the exploration of the resource was mostly due to the dynamism of the independent companies, which pioneered in the use of the new production technologies, in an environment of easy access to credit, and also in which companies could take advantage of the existing gas infrastructure, as, for example in Texas. These factors contributed to a reduction of the costs and also of the risks associated with this type of production. The rise in gas price in relation to other energy sources in this period also was an important driver of the growing interest in the subject, allied to the already mentioned decrease in the production of conventional gas in the region. With the economic crisis in mid-2008 and the fall on gas price, there was some delay in projects, particularly in more marginal regions and unconventional gas developments (WEO, 2009). But the dynamics for economic shale gas extraction have shown a great advance and natural gas producers responded by drilling with improved efficiency, resorting more frequently to horizontal wells, setting off a “shale gas rush”, and as the learning curve effects took hold, the cost to extract shale gas (including return on capital) fell even more, making additional supply available at lower cost (ACC, 2011; IHS, 2011).

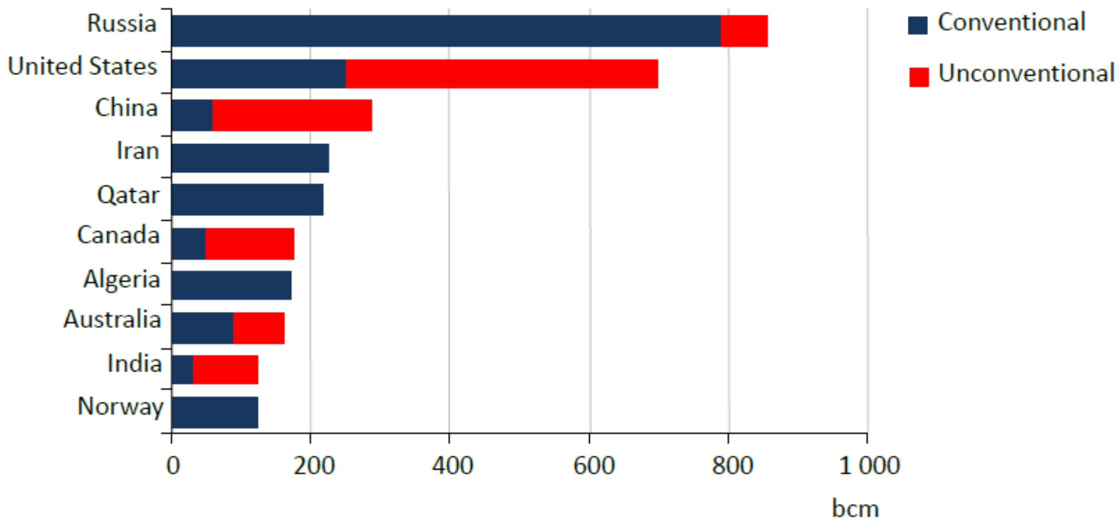
Another aspect which helped push forward the unconventional production of gas was that there was assured a market for the gas which came into production, as conventional production was slowing down and consumption, after the worse of the economic crisis was over, was on the rise. Other factors which played a role in a positive manner for unconventional production growth was the growing focus on in liquids-rich areas which contribute to improve profitability, further to other relevant initiatives such as the entrance of partners, like most of international oil companies and some national oil companies, from countries such as China, through joint ventures or acquisitions. The fact the unconventional gas production is onshore in a country with little political risk and in an institutional environment favourable to investments and entrepreneurship also played part in the growth of production led by independent companies. Although unconventional gas presently answers for only 4% of the total of global proved gas reserves, this type of gas provided almost 12% of the global production in 2008 (WEO, 2009). The United States produced approximately 75% of the unconventional gas total, having quadrupled its production since 1990 and reached about 300 billion cubic metres in 2008, more than half the gas production in the country, as shown in Figure 2 (WEO, 2009). Particularly, there was a fast rise in shale gas production in the last years.



Source: DoE/EIA after WEO, 2009

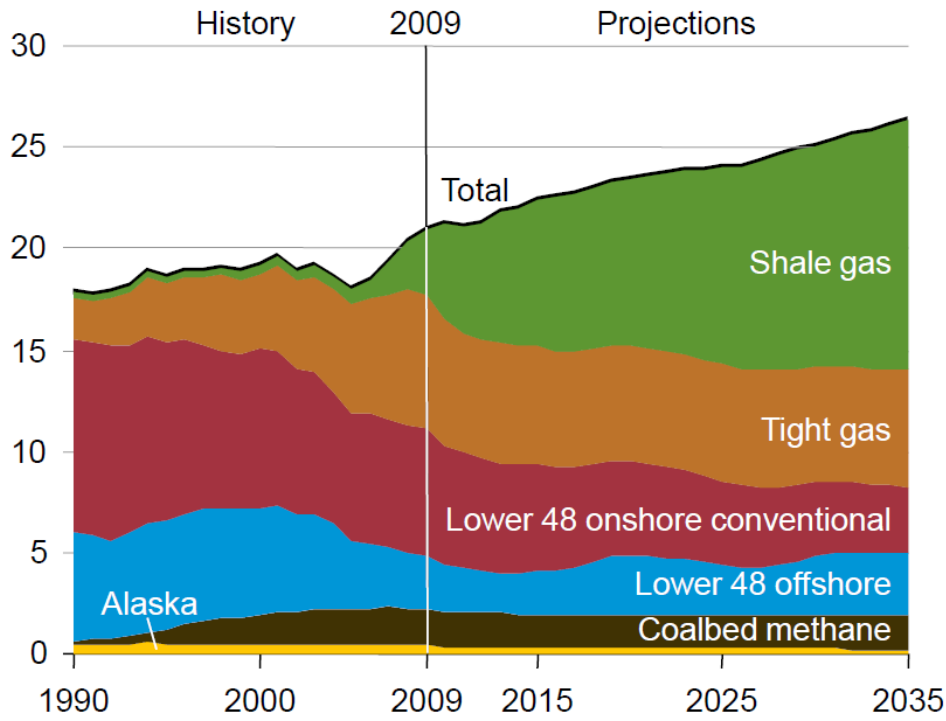
Figure 2: Unconventional gas production in the United States.

Thus, the development of unconventional gas resources strongly expanded the domestic production of the United States, with an especially relevant addition since 2008, in spite of the falling prices continued trend beginning in the second half of that year. The share of unconventional natural gas in natural gas production in the country is expected to be even more important in the production profile as indicated by several studies (WEO, 2011; IHS, 2011; AEO, 2011). For instance, from the present level of a little over half of the gas production in the country, the International Energy Agency (IEA) projects a share of almost two thirds of unconventional gas in the total gas production of the United States in 2035, as shown in Figure 3 (WEO, 2011). U.S. Energy Information Administration (EIA) forecasts that natural gas production from 2009 to 2035 in the AEO2011 Reference case results primarily from continued exploration and development of shale gas resources (Figure 4). Shale gas is the largest contributor to production growth, while production from tight sands, coalbed methane deposits, and offshore waters remains stable. Shale gas makes up 47 percent of total U.S. production in 2035, nearly triple its 16-percent share in 2009 (AEO, 2011).



Source: WEO, 2011

Figure 3: Largest natural gas producers in 2035 (volumes in billion cubic metres).



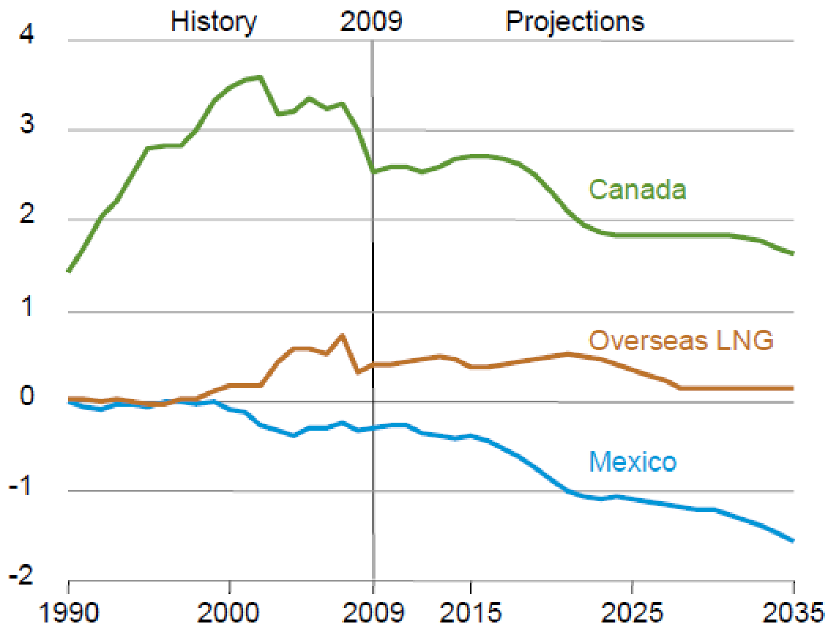
Source: AEO, 2011

Figure 4: Natural gas production by source, 1990-2035 (trillion cubic feet).

Only recently, some major and state-owned companies have increased their involvement in this business, through partnerships and/or by the acquisition of fields and independent companies. It is expected that this concentration trend will remain, given the now more limited access to credit due to the economic crisis, and the low-prices environment which affects more intensely the independent companies in the United States, already finding themselves in high leves of debt, added to the fact that the large oil companies have shown to believe in the future potential of unconventional gas and are taking this opportunity to grown in the unconventional sector.

Another factor that makes unconventional gas an energy source attractive to the United States is the security of its supply (PALTSEV et al., 2011). Thus, the country is not subjected to the instability of supply from foreign countries and the distribution system is less susceptible to disruption in supply, such as in the case of oil, resource of which the country is a great importer. Moreover, even for oil, some changes already can be seen, as the interest and economic opportunity to forgo the dependence on foreign oil is also a factor behind the growing production of shale oil and natural gas liquids, using the same techniques and human resources developed for shale gas production.

The projections of the great potential of the unconventional gas in the United States also aided in the transformation of the local gas industry, indicating that a growing portion of the domestic gas supply will come from these sources, compensating a decrease in the production of conventional gas as well as allowing a reduction in lieu of the expected large increase on liquefied natural gas (LNG) imports, which lost importance for the country’s supply, as shown in Figure 5.



Source: AEO, 2011

Figure 5: U.S. net imports of natural gas by source, 1990-2035 (trillion cubic feet).

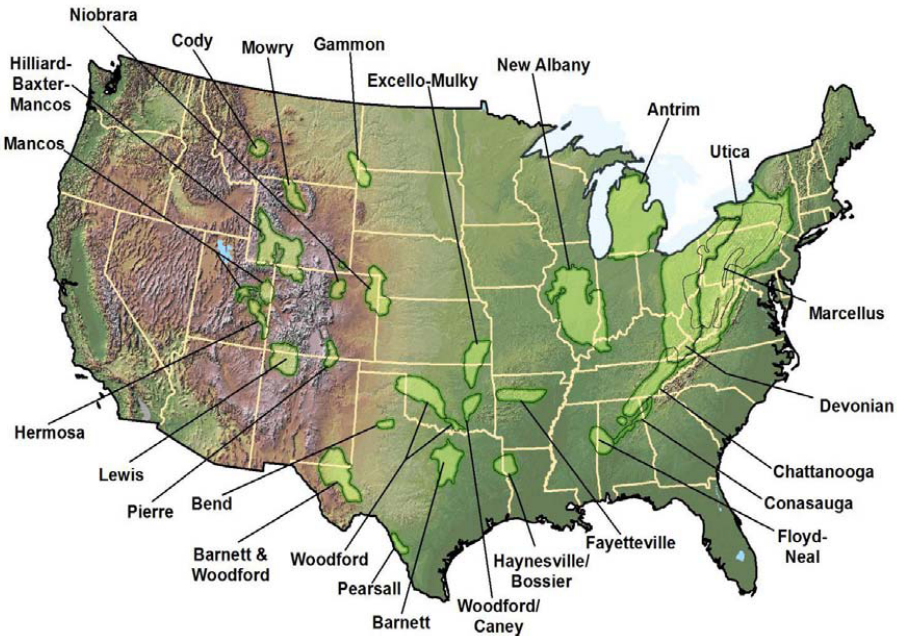
The intense transformations in the American gas production profile caused relevant changes in the outlook of the LNG import market in the country. With the advancements of the realization of the production of unconventional resources, the projections went from a scenario of growing gas deficit to another, in which this trend was reversed. This modification brings deep implications to the gas market in the United States itself as well as to the international market, as several international liquefaction projects in countries with large gas reserves as well as regasification terminals in the U.S. were developed based on a growing estimate of LNG imports by the U.S. Therefore, after these exporting liquefaction projects started, these cargoes originally directed to the U.S. now need to find other consumer countries, impacting international LNG markets, in terms of volume as well as price. Another possibility is that these cargoes will also act in the sense of "controlling" excessive increases in the natural gas price in the United States, due to the possibility and relative ease for the import thereof.

The "new" gas sources in the U.S. have the potential to increase North-American production in an estimate, in 2008 values, of a gas cost at the wellhead between US$ 3-5 per 10^6 BTU (including drilling and completion costs) for the next decades, in spite of a certain amount of pressure over prices being expected due to the cost increase of materials and of rigs contracts (IHS, 2011; CRS, 2009). Counterbalancing this effect, the recent improvements in the production per well will result in the need for drilling fewer wells and in the reduction of the drilling activity in the future, even though the high decline rates of unconventional gas require constant drilling and additional well completion to keep up the production volume (WEO, 2009).

In terms of production profile, based on shale gas production in several plays in North America, it is observed that most wells, regardless of their productivity, exhibit an early peak of production and then a rapid decline, for both vertical and horizontal wells (GÉNY, 2010). Decline rates tend to slow after several years, at a residual production level, such that most of the recoverable gas is extracted after just a few years. All shale plays and types of well have a wide range in well productivity, production rates and recoverable resources, significantly greater than those usually encountered in conventional reservoirs (GÉNY, 2010).

The United States have a wide gas pipelines system already in operation, however some new ones will have to be added in function of the new production sites, as has been happening in the last five years, especially to connect the network of exploration fields in development in the region of the Rocky Mountains and in the new area of Marcellus/Utica, further to other plays such as Bakken, with a greater focus on shale oil and natural gas liquids. As part of the unconventional gas supply is located next to the high-consuming areas in the Northeast Coast (such as Marcellus) than in the usual producing states of Texas and Louisiana, the competition between different supplier regions may affect transmission tariffs.

In the United States, one of the most promising shale gas formations is Marcellus (Figure 6), which is located along an area of about 246.000 square km and extends over six states in the Northeast of the country. Estimates indicate that about 13.85 trillion cubic metres (489 Tcf) of gas could be extracted from Marcellus, enough to provide the equivalent of more than 20 years of the country's natural gas consumption in 2008 (CRS, 2009).



Source: DOE/EIA, after CRS, 2009.

Figure 6: Main shale gas basins in the United States (without Alaska and Hawaii)

Presently, however, the development of unconventional gas has been subjected to controversies in what refers to the possible environmental impacts caused precisely by the very technologies that allowed the advancement of the production of these types of gas (ACC, 2011; AEO, 2011; IHS, 2011). Although oil and gas exploration companies have been applying such technologies in conventional oil fields for some time, only recently these were adopted in unconventional gas exploration, and also attracted a greater attention by the public opinion, because of the fast increase in drilled and fractured wells as well due to the fact that the exploration is advancing in densely populated regions.

In hydraulic fracturing, for example, water, sand and chemical products are injected under high pressure in the subsoil and a growing number of public opinion reports about the potential risk of this process to groundwater and consequently to the supply of drinkable water can be found. There is concern also that the chemical products used in the activity may harm the subsoil water quality and the fracturing may damage the aquifers. Furthermore, critics argue that the great amounts of water consumed by the hydraulic fracturing may interfere in the local water supply and that the disposal of the water extracted from the shale after the fracturing may affect the quality of the surface and subsoil water.

The present moment is, therefore, of an intense debate about the environmental issues involved in unconventional gas production. In the United States, country which is the largest unconventional gas producer, the U.S. Environmental Protection Agency (EPA) has been involved in several elucidating studies on the theme. Wastewater from shale gas extraction is prohibited from being discharged directly into any U.S. water body, according to EPA (OGJ, 2011). The Agency informed that while some is reinjected or reused, a significant amount still needs to be disposed. As a result, some shale gas wastewater is transported to treatment plants, many of which are not properly equipped to treat this kind of wastewater, according to the EPA.

The environmental challenges in unconventional gas production must be overcome and may mean that new costs would be added to the production, what could, by its turn to be counterbalanced by efficiency and productivity gains.

4. Considerations about gas prices in the United States market

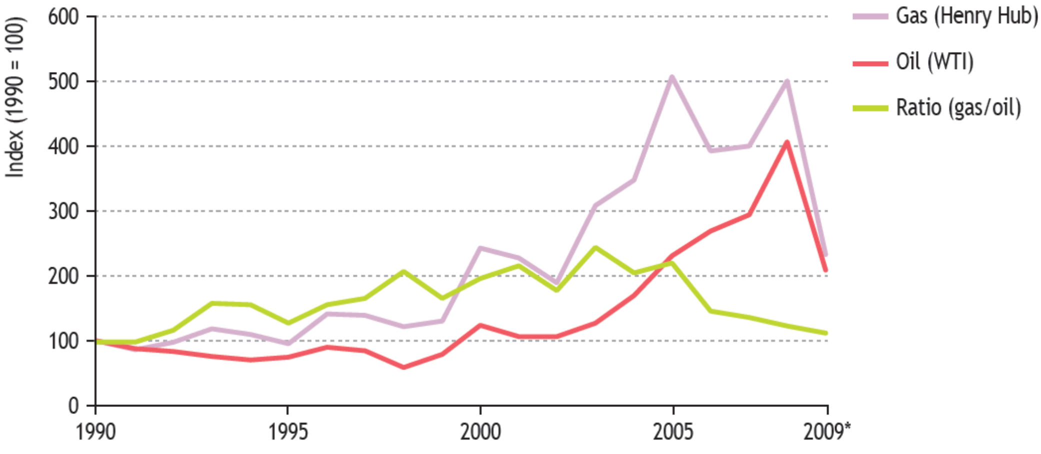
The gas price is determinant for the share of the resource in the energy mix in any market. Natural gas competes with other energy sources that may replace it in several applications, thus characterizing a competition among them. Although the flexibility in some uses is restricted, especially in the short term, the user is able to choose among the alternatives based on factors like price, existing infrastructure, supply security and the need for local storage.

Issues such as regulation and technology also affect the competition economics between energy sources. An example of this situation is a direct intervention of the Government in the energy market, such as in the in case of mandates for the use of determined types of fuels.

Natural gas shows a wide array of applications, among which the use for power generation, heating, transportation and feedstock, such as for petrochemicals and fertilisers, can be highlighted. In terms of use as a fuel, natural is gas is very versatile, having a high calorific value and, depending on the region, highly developed and easy accessed logistics infrastructure (such as is the case of the United States). Another important advantage of natural gas is the fact that it has an efficient and clean burn, emitting less greenhouse gases (GHG) than other fuels (coal, fuel oil) for the same amount of produced energy. Due to the greater concerns in society about issues related to sustainability, natural gas is also regarded as a transition fuel for less carbon-intensive world energy mixes, what creates great expectations as to the growth of future demand for this fuel. These prospects, however, are somewhat dimmed by issues regarding the environmental impacts of the technologies employed in unconventional gas exploration, specially the widely used hydraulic fracturing,

In the industry, depending on the sub-sector, gas competes with coal, oil products and power. It is mainly used in steam generation for mechanical power and in heating processes. Within the industry, the chemical sector is a leader in gas consumption (without considering the use of gas as feedstock). The substitution of gas by other fuels is simpler in the occasion of equipment maintenance or in the installation of new equipments and, specially, when gas prices are in relatively high levels.

With the increase of American natural gas reserves and the strong growth of unconventional production, further to the weak demand in the country due to the economic crisis which burst in 2008, there was a change in the balance of the local and global gas market, which reflected in a new price dynamics for the reference gas in the American market, Henry Hub. Generally, oil prices influence natural gas value mainly through their impact on the gas supply x demand balance. For the most part of the 2000s, gas prices tended to move in the same trend as oil prices. However, in the last two-three years, there was a split between gas and oil prices, in such a way so that these begun to display distinct behaviors, as shown in Figure 7.



Source: WEO, 2009.
Figure 7: Oil and Gad prices history in the United States.

Along its supply chains, the gas pricing mechanism varies according to each market. Gas prices can be calculated in many different ways: formulas, aimed more at medium and long-term contracts, which are periodically adjusted according to changes in reference prices, such as prices of substitute fuels (coal and oil, for example), cost indexes or the Henry Hub gas price itself or negotiations in the spot market for, generally, short-term deliveries.

In addition, although there is a growing trade of natural gas by pipeline and by liquefied natural gas (LNG), natural gas pricing is expected to remain region and country specific, but with a greater degree of convergence (ROSSINI et al., 2011; MATHIAS, 2008). However, this convergence did not occur as previously expected in the United States due to the actual small scale of LNG imports, which frustrated the anticipated convergence to prices more aligned to international levels. Natural gas markets are regional in nature, with the United States and Canada being an integrated regional market (ACC, 2011; IHS, 2011). For instance, consulting company IHS (IHS, 2011) considers that the U.S. Lower 48 states and Canada are considered as two components of a single North American natural gas market. Alaska is excluded because it is not integrated into the natural gas pipeline network that connects the rest of the United States and Canada. Mexico is also excluded because connections between the U.S. Lower 48 and Mexico are limited, and the Mexican gas market remains distinct from the U.S. market. In comparison, the U.S. and Canadian markets operate in close synchrony, reflecting the overall integration of the two economies (IHS, 2011)

The main drivers for natural gas demand – and, therefore, the main sources of uncertainties – are economic growth, natural gas prices and government policies. Gas has also a seasonal characteristic, having a greater degree of consumption in winter for domestic heating according to the severity of the season and in summer for air conditioning, also being dependent on the severity of the temperatures reached in the season. For example, with the economic crisis of 2008, there was a reduction in the natural gas demand and an unexpected accumulation of commercial stocks, what caused a steep fall in LNG prices and imports by the U.S.

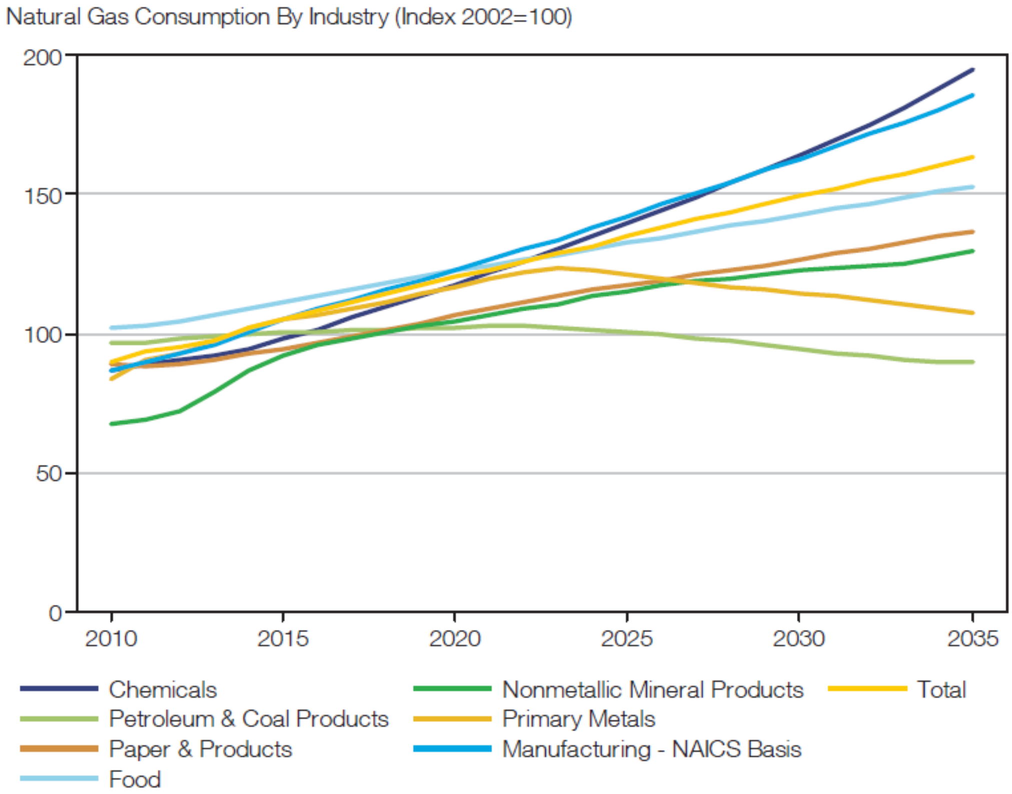
In relation to natural gas drilling activity, during the crisis a fall in the rig count was observed, however the production was not negatively impacted, largely due to the increase in the horizontal well drilling employment. The natural gas rig count started to rise again over the year 2010, from 804 at the beginning of 2010 to 929 at the end of the year (EIA, 2011). According to statistics from U.S. Energy Information Administration (EIA, 2011), horizontal natural gas-directed rigs grew about 36 percent in 2010, from 465 to 633. Directional rigs remained flat, and vertical rigs fell by 22 percent. The shift toward horizontal natural gas drilling rigs largely reflected the ongoing shift in drilling toward shale formations and the need for greater productivity in a low-prices environment.

Vertical wells constituted the majority of wells until 2008/2009 but with the introduction of horizontal wells there were a significant increase in productivity, which were essential in a depressed price environment. As a result, even as rigs are far below levels reached in 2008, production has continued to grow (EIA, 2011).

Another point is that the natural gas share in power generation is very sensitive to the relative price of gas in comparison to other fuels and technologies. More uncertainties regarding the demand for natural gas arise by the introduction and increase of carbon prices that, for example, could contribute for an advantage in the use of natural gas in relation to coal, considering other variables all equal.

By analyzing the demand side, the present consumption profile of natural gas in the U.S. shows that the main use and with better growth prospects is for power generation, but industrial and residential consumers also have relevant shares in the consumption (IHS, 2011). In addition, economic activity in the U.S. is an important variable when forecasting the energy mix because as the U.S. economy becomes more service-oriented, its energy intensity is declining.

Consulting company IHS Global Insight (IHS, 2011) expects five of the six most gas-intensive industries to grow more slowly than the average for all manufacturing industries, which will suppress growth in their demand for natural gas. The chemicals industry, in a contrary trend, faces heavier U.S. demand for its wide-ranging products. This industry has a good exporting basis and is able to take advantage of growing supplies of NGL feedstocks in the United States, with projections to grow faster than all industries after 2030 (Figure 8). Were it not for the expected growth in petrochemical demand, total industrial gas demand would be in a long-term decline. Instead, it is expected to remain flat over the long term (IHS, 2011).



Source: IHS, 2011

Figure 8: U.S. Outlook for Natural Gas-Intensive Industries

4.1 Perspectives for natural gas prices in the United States and its consequences for petrochemical feedstock prices

One of the more interesting developments in the last five years has been the dynamic shift in natural gas markets. Between the mid-1960s and the mid-2000s, proved natural gas reserves in the United States fell by one-third, the result of restrictions on drilling and other supply constraints (IHS, 2011). Starting in the 1990s, the Government promoted the use of natural gas as a clean fuel, and with fixed supply and rising demand from electric utilities, a natural gas supply shortage occurred, causing prices to rise from an average of US$1.97 per 10^6 BTU in the 1990s to US$7.51 per 10^6 BTU in 2005. Rising prices were exacerbated by the effects of hurricanes Katrina and Rita in 2005, which sent prices over US$12.30 per 10^6 BTU for several months due to damage to gas production facilities (ACC, 2011).

In 2010, as high oil prices have widened the gap with natural gas prices (which reflect a well-supplied market and the insofar impossibility to freely export gas, reinforcing the regional character of the market), operators have ramped up activity in liquids-rich plays such as the Eagle Ford Shale, Marcellus Shale, and the Bakken formation in North Dakota in order to obtain more profitability derived from liquids price related to oil prices (IHS, 2011).

As described before, natural gas prices are regional while oil prices are part of an international market that is subject to other dynamics and variables. Some factors that influence oil prices are not directly present in gas markets, at least to the same degree, for instance, spare capacity, OPEC quotas and refining capacity.

Also, the global outlook for gas utilization seems to be very positive, reinforced by the following global trends:

- Continued debate for the reduction of greenhouse gases emissions;
- Review of nuclear power in Japan, North America and Europe;
- Continued interest by countries and companies in energy security and diversification (ROSSINI et al., 2011).

Some institutions like BP (BP, 2011), EIA (AEO, 2011) and consulting company IHS (IHS, 2011) indicate that the electric power sector will be the primary driver of natural gas demand for the long term, albeit competing directly with coal, which then sets an important parameter for gas prices. Environmental regulations, renewable energy mandates, and economics all work to promote increased gas use for power generation. Environmental Protection Agency (EPA) regulations aimed at restricting emissions of sulfur, mercury, particulate matter, and potentially carbon dioxide are increasing the costs of operating coal generation units and, in some cases, are hastening their retirement. Natural gas is a cleaner burning fuel than coal, with only half the carbon content, and is increasingly being favored over coal for power generation (IHS, 2011).

The growth of shale gas is leading to lower natural gas (and electric power) prices and increased productivity:

• The full-cycle cost of shale gas produced from wells drilled in 2011 is 40-50% less than the cost of gas from conventional wells drilled in 2011.;

• Without shale gas production, reliance on high levels of liquefied natural gas (LNG) imports would influence U.S. natural gas prices, causing them to increase by at least 100%.;

• The lower natural gas prices achieved with shale gas production will result in an average reduction of 10% in electricity costs nationwide over the forecast period.;

• By 2017, lower prices will result in an initial impact of 2.9% higher industrial production. By 2035, industrial production will be 4.7% higher. (IHS, 2011)

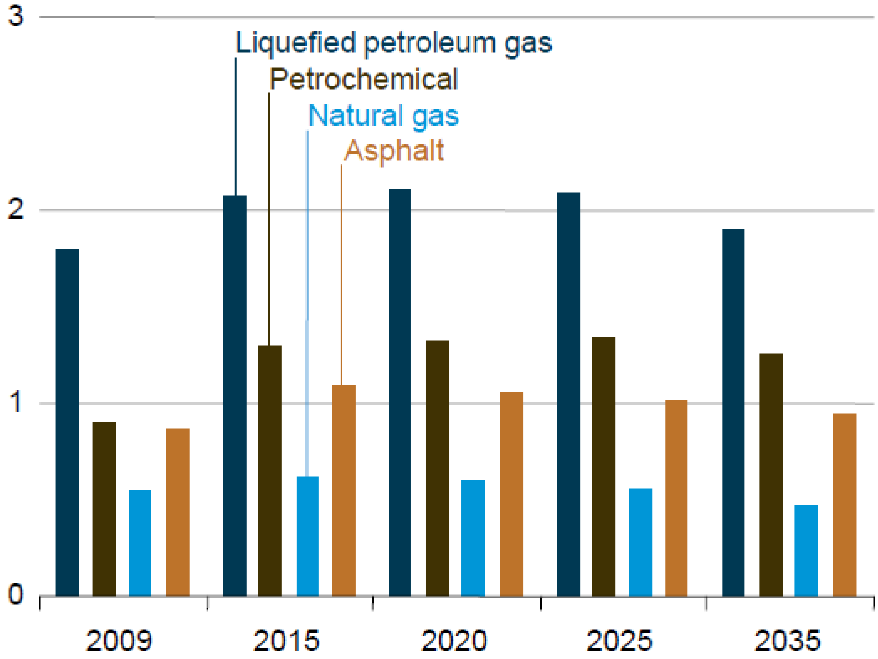
Shale gas resource in the United States is now available at a low cost and the supply curve for natural gas has become relatively elastic (IHS, 2011). The U.S. natural gas resource base can now accommodate significant increases in demand without requiring a higher price to elicit new supply. For instance, consulting company IHS estimates that almost all of the U.S. shale gas resource could be developed at a full-cycle cost of US$4.1 per 10^6 BTU Mcf or less. Cost calculation includes credit for revenues from the sale of natural gas liquids that are produced with the gas and used primarily as inputs to the petrochemical industry (IHS, 2011).

In relation to the efforts to increase gas use in trucks and automobiles, consulting company IHS estimates that direct vehicle use of natural gas may grow from a small base to just under 1 Bcf per day in the next 25 years, but gas may also be used to produce power for electric vehicles and indirect vehicular gas use would show up as power-sector gas demand (IHS, 2011). Additionally, some believe that the spread between oil and natural gas prices will be great enough to stimulate gas demand for transportation, beyond bus, truck, and car fleets. But, even if the IHS CERA outlook proves to be overly conservative, additional transportation gas demand is unlikely to strain supply to the market or the price outlook used here (IHS, 2011).

The industrial sector may hold additional growth potential. For instance, a number of chemical companies have announced plans to expand their U.S. operations as petrochemical production relies on natural gas as a process fuel. Prospects for other gas-intensive industries are more limited (IHS, 2011).

For the consumption of hydrocarbon resources as industrial feedstock, which includes the use of asphalt and road oil in the construction industry as well as use of liquid petroleum gas, naphtha, petroleum gas oil, and natural gas as raw materials for the production of various chemicals, it is also expected growth of the latter due to more unconventional gas supply in the country. The largest share of feedstock consumption occurs in the chemical industry, primarily for the production of ethylene and propylene (mainly used to make plastics), fertilizers, and a variety of inorganic chemicals (AEO, 2011).

Industrial energy consumption trends in the report Annual Energy Outlook 2011 - Reference case (AEO, 2011) reflect growth in consumption of all feedstocks after the 2008-2009 economic downturn, followed by a long-term decline as production of basic chemicals falls. Increased use of ethane and propane as alternatives to naphtha and gas oil reflects a recent switch to lighter feedstocks with the rise in crude oil prices relative to natural gas prices (AEO, 2011). With increasing production of natural gas and natural gas liquids (NGLs), lighter feedstocks become readily available on a continuing basis (Figure 9).



Source: AEO, 2011

Figure 9: Industrial consumption of fuels for use as feedstocks by fuel type, 2009-2035 (quadrillion BTU).

Based on AEO 2011, consumption of all feedstocks is higher in 2035 than in 2009, except for natural gas, which drops by 14 percent from 2009 to 2035. The use of natural gas as a feedstock falls after 2014, when domestic production of hydrogen, methanol, and ammonia begins a decline that continues through 2035. Ammonia production declines as a result of modest growth in agricultural production and increased foreign competition. Consumption of asphalt and road oil increases through 2016, then declines with slower growth in the construction industry. As the U.S. economy becomes more service-oriented, its energy intensity is declining (IHS, 2011).

Since natural gas liquids are only a small fraction obtained from bulk natural gas production and that the use of natural gas as a petrochemical feedstock will not be the main driver for natural gas production in the long term, there is evidence that use of natural gas liquids for chemicals production will not be able to have great impact on natural gas prices. But it is important to mention that some shale gas formations, including Eagle Ford and parts of Marcellus are rich in natural gas liquids and these natural gas liquids help maintain the profitability of the gas exploration. By providing a market for the co-produced natural gas liquids, ethane in particular, shale gas production actively seeks alternatives to remain economic (ACC, 2011).

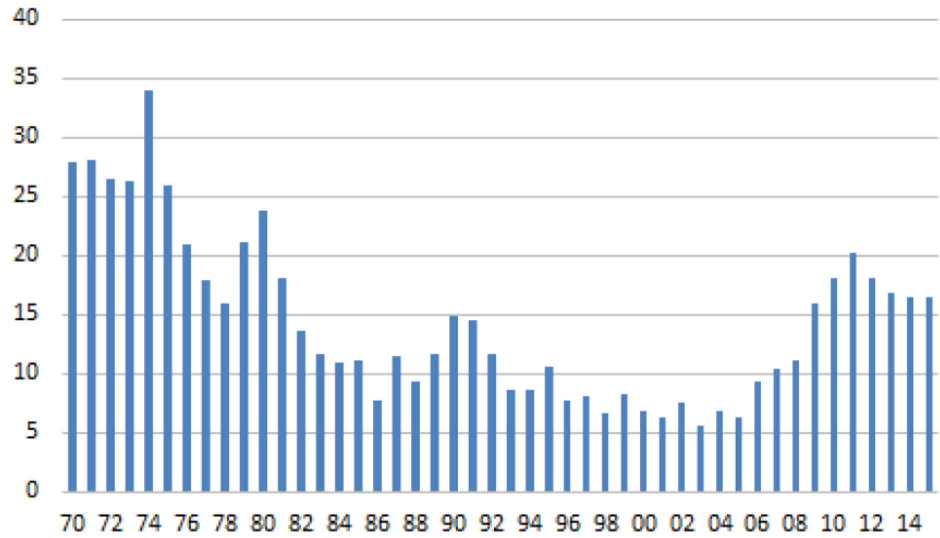
The price of ethane is correlated with U.S. natural gas prices (Henry Hub). As a result, prices for ethane tend to parallel the price for natural gas but the correlation has weakened in recent years and other explanatory variables such as the prices of alternative feedstocks (like propane, butane, and naphtha) are also important. However, the growing natural liquids production could reinforce the link of ethane prices to gas prices. Propane, butane and naphtha prices tend to be correlated with the price of oil because these streams can also be supplied by this resource (ACC, 2011). So ethane pricing is more regional while naphtha prices tend to be more internationalized.

The price of naphtha, gas oil and other light distillate oil-based products are related to the price of oil, a commodity with prices set by global supply and demand. The price of naphtha (in Western Europe, for example) is highly correlated with the price of oil (Brent). As a result, prices for naphtha will parallel the price for oil (ACC, 2011).

As a rough rule of thumb, when the ratio of the price of oil to the price of natural gas is more than 7:1, the competitiveness of Gulf Coast-based petrochemicals and derivatives vis-à-vis other major producing regions is enhanced (ACC, 2011). This competitiveness arises from the presence of flexible cracker units in Gulf Coast. In the United States, more than 75% of ethylene, for example, is derived from natural gas liquids while in Western Europe over 70% is derived from naphtha, gas oil and other light distillate oil-based products (ACC, 2011; POTTER, 2010; SHARMA, 2010). Other analysts estimate that ethane alone accounts for over 60% of total current production of ethylene in the U.S. (IHS, 2011; FERNANDO, 2010).

Thus, the feedstock costs (and relative competitiveness) of cracking ethane and naphtha will follow the respective costs of natural gas and oil. Historically, other factors (co-product prices, exchange rates, capacity utilization, etc.) have played a role as well. This shift toward more and lower-cost natural gas (and disconnect of its relationship with oil prices) has benefitted the U.S. chemical industry, resulting in greater competitiveness and heightened export demand. This helped offset downward pressures during the recession (ACC, 2011).

Figure 10 shows history and medium-term trend in the oil-to-gas ratio, from 1970 through 2015 according to a report from American Chemistry Council (ACC, 2011). The early-2000s represent a period in which U.S. petrochemicals were facing competitive challenges. This was in contrast to the 1970s and the period through early-1990s, when U.S. natural gas prices were low and oil prices were high, the latter as a result of the Gulf War. In the 1990s, the U.S. energy policy favored use of natural gas in electricity generation but did little to address supply. In late-2000, the first of several large price spikes occurred, resulting in higher U.S. natural gas prices as U.S. supply was constrained. This continued during the next five or so years, with subsequent natural gas price spikes pushing the oil-to-gas ratio down to levels associated with non-competitiveness. At that time there were numerous concerns about the long-term viability of the U.S. petrochemical industry (ACC, 2011). Moreover, a number of plant closures occurred during this period and investment flowed to the Middle East and to Asia with world scale greenfield projects. But positive prospects of shale gas use for petrochemicals are expected to rejuvenate the local petrochemical industry and provide competitiveness based on lower feedstock costs.



Source: ACC, 2011

Figure 10: Oil-to-Gas ratio: a proxy for U.S. Gulf Coast competitiveness (WTI in US$/bbl divided by natural gas in Henry Hub in US$ per 10^6 BTU)

Between 2009 and 2010, as shale production started to ramp up in significant volumes, the price average has dropped from US$6.73 per 10^6 BTU (average 2000 - 2008 Henry Hub Price) to US$4.17 per 10^6 BTU in constant 2010 dollars (IHS, 2011). Natural gas prices are and will continue to be over two times lower than they otherwise would have been prior to the shale gas boom. Moreover, from 2011 through 2035, IHS projects that the price will average US$4.79 per 10^6 BTU in constant 2010 dollars (IHS, 2011)

The U.S. Energy Information Administration (EIA), in its Annual Energy Outlook 2011 (AEO, 2011), also believes that unlike crude oil prices, natural gas prices will not return to the higher levels recorded before the 2007-2009 recession (Figure 11). Although some supply factors continue to relate the two markets loosely, they lost the high connection level observed in the last few years prior to the 2008 crisis (Figure 12). The large difference between crude oil and natural gas prices results in a shift in drilling toward shale formations with high liquids concentrations (AEO, 2011) and leaves positive prospects for expanding NGLs supply in the United States.

However, the prospects of a further shift towards shale and tight oil production with increasingly more oil-directed wells could impact gas and even NGLs production and eventually might affect the U.S. petrochemical industry in ways that as for now are not clearly foreseeable.

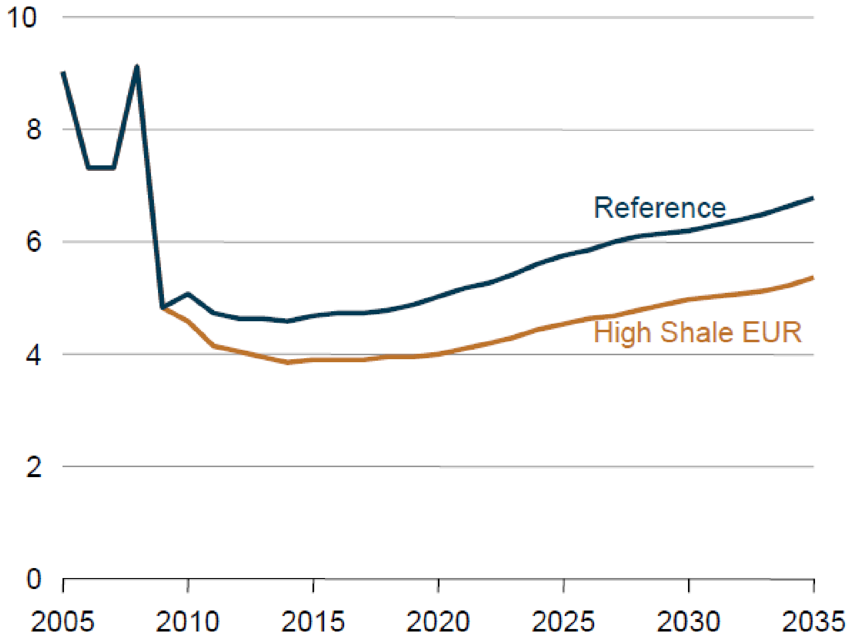


Figure 11: Annual average lower 48 wellhead and Henry Hub spot market prices for natural gas for Reference case and High shale EUR case[1], 1990-2035 (2009 dollars per 10^6 BTU)
Source: AEO, 2011

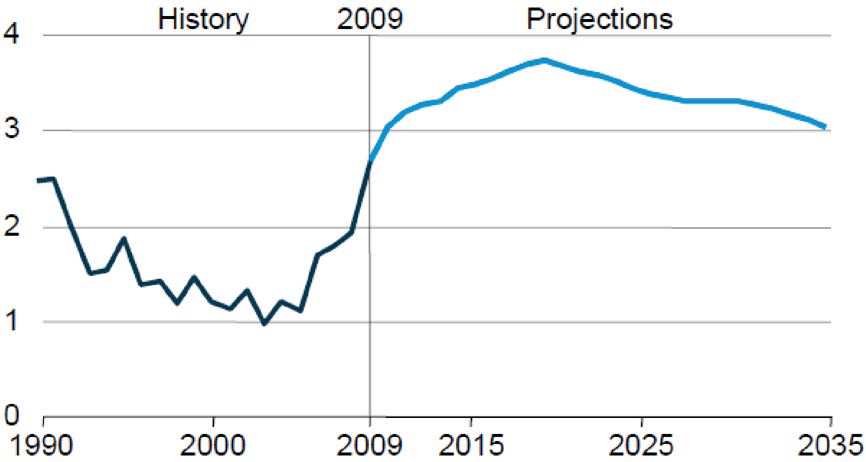


Figure 12: Ratio of low-sulfur light crude oil price to Henry Hub natural gas price on an energy equivalent basis, 1990-2035
Source: AEO, 2011

Nevertheless, the EIA deems that gas continues to have enormous potential and to satisfy consumption levels in the Reference case of AEO 2011 report, the number of Lower 48 natural gas wells completed increases by 2.3 percent per year from 2009 to 2035. As a result, the average wellhead price for natural gas increases by an average of 2.1 percent per year, to US$6.26 per 10^6 BTU in 2035 (2009 dollars). Henry Hub prices increase by 2.3 percent per year, to US$7.07 per 10^6 BTU in 2035. Nonetheless, the Henry Hub price and average wellhead prices do not pass US$5.00 per 10^6 BTU until 2020 and 2024, respectively

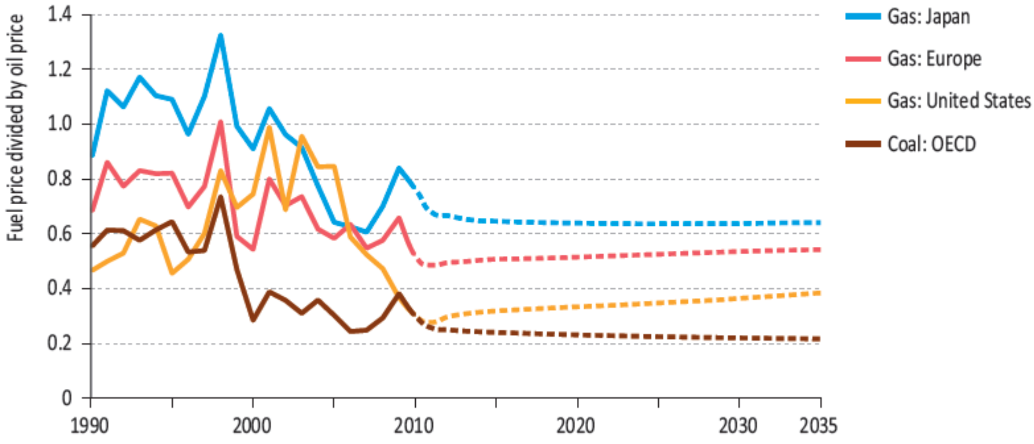
[1] In the High Shale EUR case, the estimated ultimate recovery (EUR) per shale gas well is assumed to be 50 percent higher than in the Reference case. The higher estimate could result from, for example, better placement of the horizontal lateral within the formation; better completion techniques that allow more of the pore space and absorbed gas to reach the well bore; and/or determination that well recompletions are both productive and economic (AEO, 2011).

(AEO, 2011). These projections are close to the IHS ones (IHS, 2011) but show an increasing difference in the medium to long-term.

The International Energy Agency, on its annual report World Energy Outlook 2011 (WEO 2011), also elaborates forecast price for natural gas but long-term price level is higher than one for IHS (IHS, 2011). IEA analyses that in a growing number of markets gas prices are set freely in a competitive gas market, an approach known as gas-to-gas competition. IEA indicates that prices are set in this way in North America, the United Kingdom and Australia and, increasingly, in Continental Europe, accounting for some three-quarters of total Organisation for Economic Co-operation and Development (OECD) gas use.

According to the IEA (WEO, 2011), differences in pricing mechanisms inevitably lead to differences in the actual level of prices. The level of gas prices under gas-to-gas competition depends on the supply/demand balance in each regional market, including the prices of all competing fuels. Over the past few years, U.S. natural gas prices have fallen relative to oil prices, because of a glut of gas caused by the boom in unconventional gas. The Agency projects that North American gas prices recover slightly, relative to oil prices, over the projection period (through 2035), largely reflecting expectations that gas production costs there will tend to rise as production shifts to more costly basins.

The growing share of LNG in global gas supply and increasing opportunities for short-term trading of LNG are expected to contribute to a degree of convergence in regional prices over the projection period, but significant price differentials between the United States, Europe and Japan are expected to remain, reflecting the relative isolation of these markets from one another and the cost of transport between regions (Figure 13), further to the loss of relevance of LNG for U.S. supply. The central scenario for this price projection is the New Policies Scenario, in which recent government policy commitments are assumed to be implemented in a cautious manner – even if they are not yet backed up by firm measures (WEO, 2011).



Note: Calculated on an energy-equivalent basis.

Figure 13: Ratio of average natural gas and coal import prices to crude oil prices in the New Policies Scenario
Source: WEO, 2011

The IEA has revised downwards its natural gas price assumptions in relation to the previous annual report because of improved prospects for the commercial production of unconventional gas. For the IEA, although gas prices broadly follow the trend in oil prices, the ratio of gas to oil prices on an energy-equivalent basis remains below historical averages in all regions, particularly in North America (WEO, 2011).

Gas prices are assumed to vary across the IEA scenarios in line with the degree of policy effort to curb growth in energy demand. In the New Policies Scenario, prices reach US$12 per 10^6 BTU in Europe, US$14 per 10^6 BTU in the Pacific and US$9 per 10^6 BTU in North America by 2035 (in real 2010 dollars). In the Golden Age of Gas Scenario (GAS Scenario), prices are assumed to be up to US$1.50 per 10^6 BTU lower than in the New Policies Scenario, largely because of the scenario's more optimistic assumptions about future gas supply (WEO, 2011).

Price projections shown in this article were only briefly explained and it is strongly advisable to access mentioned reports in order to have a better understanding of assumptions and methodology applied. Important results from these projections are that analysed agents in the oil and gas industry forecast that natural gas in the United States price levels shall remain in low levels when compared to oil prices and it evidences that ethylene producers may have a cost advantage due to low price feedstock in the global petrochemical industry.

5. The use of gas as a feedstock for petrochemicals and fertilisers

In the petrochemical industry, the interest in the use of gas as a feedstock is based on the fraction C2+, that is, in the ethane and heavier hydrocarbons contents, which will serve as feeds for the traditional process of steam cracking (or pyrolysis). The obtained yield is, predominantly, light olefins, such as ethylene and propylene. Another traditional feedstock for the petrochemical industry is naphtha, which produces a greater variety of products and has a smaller ethylene yield than natural gas. However, some steam crackers have the possibility of using gaseous feeds as well as liquid feeds (for example, ethane or petrochemical naphtha), what allows, to a certain extent, an arbitration in relation to the choice of the feedstock to be used, according to the profile of desired production and the raw materials and final products price levels.

The usual feedstocks for the production of light olefins can be divided in liquid or gaseous feeds. Examples of gaseous feed, whose price dynamics tends to be more linked to the variations in natural gas price, are ethane, propane, ethane-propane mix, refinery gas and liquefied petroleum gas (LPG). Liquid feeds, with prices linked to oil prices, can be petrochemical naphtha, natural gas liquids (C2+), gasoil (coming from atmospheric distillation and vacuum distillation), FCC and HCC (hydrocatalytic cracking) streams.

The business of chemistry is energy-intensive. This is especially the case for basic chemicals, as well as certain specialty chemical segments (for instance, industrial gases). The largest user of energy is the petrochemical and downstream chemical derivatives business. Inorganic chemicals and agricultural chemicals also are energy-intensive (ACC, 2011).

As noted before, main feedstocks for production of ethylene in the U.S. are ethane and propane derived from natural gas liquids. While propane has additional non-feedstock uses, such as fuel, the primary use for ethane is to produce petrochemicals; in particular, ethylene (ACC, 2011). Ethane is the feedstock with the highest yield into ethylene. Cracking of naphtha produces a more diverse series of petrochemicals, including aromatics, although it produces less ethylene for the same feedstock amount. One additional point is that cracking of ethane requires simpler unit operations than cracking of naphtha, leading to lower operational costs. So, when considering feedstock and operational costs for the production of one ton of ethylene, there is a clear cost advantage for the manufacturers processing gaseous feeds.

Ethane is difficult to transport, so it is unlikely that the majority of excess ethane supply would be exported out of the United States, even if exports become allowed, due to the growing shale gas production. As a result, it is also reasonable to assume that the additional ethane supply will be consumed domestically by the petrochemical sector to produce ethylene. In turn, the additional ethylene and other materials produced from the ethylene are expected to be consumed downstream, for example, by plastic resin producers (ACC, 2011).

Increased ethane availability is already occurring as gas processors build the infrastructure to process and distribute production from shale gas formations. According to the Energy Information Administration (EIA), ethane supply has already grown by roughly 20%. Chemical producers are starting to take advantage of these new ethane supplies with crackers running at 95% of capacity, and several large chemical and petrochemical companies have announced plans to build additional capacity. Given the high importance of feedstocks to the cost of petrochemical production and owing to the fact that U.S. have plants which were able to have their feedslate converted to gaseous raw materials, as the price of ethane is low relative to oil-based feedstocks used in other parts of the world, US-based chemical manufacturers gained in competitiveness and are contributing to strong exports of petrochemical derivatives and plastics. In 2010, exports in basic chemicals and plastics were up 28% from 2009. The trade surplus in basic chemicals and plastic surged to a record US$16.4 billion (ACC, 2011)

In the nitrogen fertilizer industry, natural gas is also used both as key feedstock, based mainly on methane, and as fuel for furnaces etc. Between 1999 and 2006, the North American ammonia market consolidated around one-third of its nameplate capacity but operating rates in 2011 are estimated to be around 90% of capacity. Lower natural gas prices in this region supported production volumes for 2011 to be anticipated to satisfy around 73% of domestic demand, with the remaining 27% being satisfied by imports, primarily from low-cost South American producers, mainly in Trinidad (IHS, 2011).

6. The petrochemical industry in the United States

Presently, in the United States, the main feedstock for the production of ethylene is ethane, differently from Europe, with a mostly naphtha-based petrochemical production. The country is a traditional producer of olefins and aromatics, with a production capacity of nearly one quarter of global capacity for both chemicals. In terms of the increase in production capacity in the U.S., an important expansion in the industry in the next 5 years is starting to be considered by the main players. Regarding the plants currently in operation, their feedstock choice occurred in connection to the prices outlook and production projections current at the time of their implementation. In the 1950s and 1960s, due to the declining gas production at the time, many investors preferred to build naphtha and gasoil-based ethylene production plants. In the middle of the 1970s, in the occasion of the rise in oil prices, natural gas was the preferred option for new plants (FERNANDO, 2010).

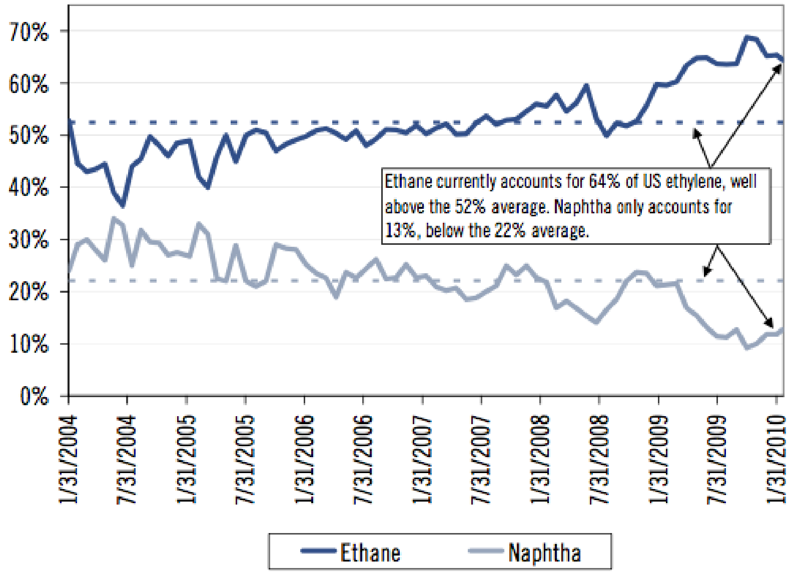
In the U.S. Gulf Coast, there are several flexible steam crackers, which can use liquid feeds, such as naphtha, or gaseous feeds, such as ethane. Due to these flexible crackers, the petrochemical feedstock demand in the U.S. Gulf Coast may change according to the relative prices of gas versus oil prices. For example, an increase in the oil-gas spread encourages a change of oil-based feeds to the cheaper feedstock, gas. Generally, the larger resulting demand leads to a consequent increase in the ethane price, with the other variables all equal, what would tend to rebalance the share of feedstocks at historical levels. However, considering that the variables which affect the petrochemical feedstocks coming from oil or natural gas are not always the same, there can be structural changes in these relationships, as is the case with crescent expectations of ethane availability. Historically, in the United States, the liquid feed and gaseous feed crackers margins have been similar. However, for the calculation of the return on capital it is necessary to consider that higher investments are required for the implementation of a liquid feed cracker plant and that those have higher operation costs, what puts the gaseous feed crackers in an advantage in this topic.

The increased volatility and growth of natural gas prices between 2000 and 2006 (a shock period) negatively impacted the chemicals industry. Back in 1997, sources of conventional natural gas were maturing (mainly gas taken as a byproduct of oil extraction), demand was expanding, and oil prices were declining, putting pressure on the competitive cost structure of chemicals producers in the United States. Foreseeing future scarcity in the natural gas market, these companies opted to move their operations closer to abundant and inexpensive sources of feedstock (IHS, 2011; SANTOS, RAMOS, 2010). Companies like Dow Chemical spent a decade moving production to the Middle East and Asia. The last cracker to be built in the United States became operational in 2001 (IHS, 2011). Currently, however, the company plans to aggressively expand production capacity in the United States to take advantage of the low prices of natural gas promoted by shale gas exploitation, including plans for a new world-scale cracker in the U.S. Gulf Coast by 2017 (SANTOS et al., 2011).

In 2001, seasonal extreme weather conditions and tight supplies of natural gas caused strong price increases. The U.S. chemicals industry responded to high natural gas prices by either converting existing ethane and/or propane (EP) olefin cracker capacity to accommodate heavier feedstocks, such as naphtha, or shutting down EP feedstock crackers in the United States and moving manufacturing facilities that produced ethylene, propylene and ammonia closer to sources of cheap feedstock: ethane from distressed natural gas wells in the Middle East and naphtha in Asia. The preference for naphtha relied on low oil prices at the time, showcasing the importance of relative prices in determining the economic impact of a high natural gas price scenario (IHS, 2011).

However, with the continuous fall in the gas/oil ratio in terms of BTU parity in the United States, crackers had a greater incentive in the use of light feeds in their furnaces. This made the share of ethane in ethylene production in the United States to be more advantageous and to surpass historical averages, advancing over the naphtha share, as show in Figure 14. In relation to naphtha, coming from refineries according to specifications for its use as a petrochemical feedstock or to take part in the gasoline blend, the continuation of the path of its price linked to that of oil is observed. Furthermore, the United States are a large gasoline consumer market, a fuel that answers for a relevant share of the country's oil consumption. Therefore, the price of gasoline also has some influence over the price of naphtha and vice-versa, as this range of products can be directed either way.

Another issue that must be carefully regarded is the ongoing reduction in U.S. domestic demand for gasoline, due to the economic situation,the greater use of ethanol and new standards for fuel efficiency, for instance. This fact allied to the growing production shale and tight oil might have an influence on the outlook for gasoline and naphtha prices. Shale oil and tight oil have high API degrees having the potential to produce more light and medium distillates, such as those in the LPG and naphtha ranges.



Source: Citi Investment and CMAI after FERNANDO, 2010

Figure 14: Ethylene production sources in the U.S. (2004-present).

In relation to the maintenance of the United States as an exporter of ethylene-derived resins as per the earlier projections according to which the country would be an importer in the short-term, it is noteworthy that macroeconomic factors played a relevant role in this situation. The economic crisis that affected the country in 2008, inhibiting economic growth, had reflexes in the demand for final products produced from petrochemicals, consequently affecting the domestic demand for the latter and making more volumes available for export.

Furthermore, there were some permanent closures of some non-competitive (old and low-scale) petrochemical plants as well as temporary interruptions in the operation of some units in the country during the peak of economic crisis, what contributed to a petrochemical supply x demand balance that was unfavorable to crackers at the time.

Thus, the trend that the United States would become a net polyethylene importer, starting from 2010, could be reversed and delayed in time. It is now forecast that the most part of the domestic demand of the United States will be met by local production. Producers with feedstock gains and also with conversion efficiency are expected to keep their competitive advantages. In 2009, polyethylene exports from the United States reached 3.3 million ton. In 2010, exports continued to grow. Even with the significant increase in exports from the Middle East, which shall almost triple from 4.5 to 11 million ton/year, market analysts believe that the United States will remain exporting in the period considered in this analysis, that is until 2014 (FERNANDO, 2010; POTTER, 2010). Possible destinations for United States exports are importing markets in nearby regions, such as Mexico and South America, this later region with its petrochemical production being mostly based on naphtha.

So, according to these estimates, given the gas reserves of the United States, the present production costs advantage over Europe and Asia (particularly, Japan and South Korea) shall continue. Even Canadian chemical companies already are making movements in order to create an infrastructure to access unconventional gas in the United States while the Canadian unconventional production does not overcome its challenges, affected by the distance to consumer markets and low gas prices. However, due to large additions in capacities in the Middle East and China, some capacity in Europe, in said Asian countries and in the United States may close in order to compensate for the entry of these new volumes of petrochemicals, in an attempt of a rationalization in the industry.

Because of this cost advantage of producing ethylene from natural gas, it is expected that the United States expand their focus on the production of this chemical building block. But it is also necessary to discuss the impacts that this decision may cause in the balance of other chemical building blocks, such as propylene. Propylene is the most widely used basic petrochemical after ethylene, produced as either a by-product of ethylene in steam crackers or from gasoline/distillates in the FCC unit of an oil refinery. Its main demand driver is polypropylene production. For some applications, both polyethylene and polypropylene can be used and cost benefit analysis will determine which one should be used.

When focusing on ethylene production through cracking of gaseous feed instead of liquid ones, there is also a change on the product profile forward to ethylene production and it has consequences for the balance of chemicals in the market. Another interesting aspect in relation to the propylene production is that ethanol use in the United States may reduce domestic demand for naphtha, as mentioned before, and consequently refiners could run FCC units with lower operational factors. Then refinery propylene production could be affected. One possibility is to run FCC within a certain idleness but using catalysts and operational conditions to improve production of light olefins, though.

In Mexico so far unconventional gas production has not reached levels compared to those of the United States, being virtually nonexistent. So, forthcoming projects aiming at reducing the deficit in polyethylene consumption in the country which is currently being met by imports, will rely on contract-based ethane supply with the Mexican state-owned company, from conventional sources.

Regarding Canada, the recent growth in petrochemical production was located in Alberta, where the conventional gas production is declining, what brings poor prospects for any future investments. Unconventional gas would give Canada some new options for petrochemical production, but as above mentioned, the country is facing challenges to develop these reserves due to the low price scenario and the distance of the reserves in British Columbia from consumer markets. For plants located in Ontario there are efforts to secure additional feedstocks from the nearby Marcellus shale, what could also reinvigorate the petrochemical cluster in the Sarnia area (INDUSTRY CANADA, 2011).

However, this resurgence in the petrochemical industry in the U.S. can face challenges in the form of imported finished goods. In this case, the transformed products, such as bags, packages, films and auto parts, among others, may reach the United States by means of imports from Asia and, in particular, from China, destination of resin exports from the Middle East producers. The polyethylene producers from the Middle East enjoy a cost advantage over other producers in the world, albeit decreasing in comparison to U.S. ethylene production. As Asian labour costs are relatively low when compared with ones in the North America and Europe and third-generation petrochemicals such as non-durable goods are highly labour intensive, Asian manufactures also enjoy advantages in their production. Therefore, the North-American domestic demand for plastics products could be affected by the competition with transformed goods.

In relation to shale gas formations in the U.S., to date, the Barnett, Haynesville, and Woodford basins have received the most attention (ACC, 2011; AEO, 2011; IHS, 2011). But shale gas formations differ from each other in relation to NGLs content. In a report entitled "Shale gas and new petrochemicals investment: benefits for the economy, jobs and U.S. manufacturing", the American Chemistry Council (ACC) (ACC, 2011) explores and analyzes the possibilities and impacts of shale gas for the petrochemical industry (ACC, 2011).

Haynesville is reported to be mostly dry, while Barnet has dry and rich NGL regions. The Eagle Ford shale formation in Texas is close to the existing petrochemical industry and infrastructure and portions thereof are reported to be rich in ethane and other NGLs (ACC, 2011). The liquids content adds another layer of complexity and economic attractiveness to the shale gas growth story due to the possibility to value these streams in a ratio linked to oil prices. For ethane, although more linked to gas prices, it has higher margins, as previously mentioned .

More recently, the Marcellus basin (by some estimates the largest known shale deposit in the world) has witnessed significant development. Portions of this formation are rich in NGLs but at a distance from the Gulf Coast where much of the existing petrochemical industry exists. Significant development of infrastructure (pipelines, ethane recovery, etc.) would be needed and could also include investment in petrochemical and derivatives capacity. Thus, areas in western Pennsylvania, New York and/or West Virginia could become the next U.S. petrochemical hub. The governor of West Virginia, for example, has recently formed the Marcellus to Manufacturing Task Force to harness business opportunities surrounding development of the Marcellus basin. Also, the Eagle Ford shale formation in Texas is close in location to the U.S. petrochemical industry (and infrastructure) in the Gulf Coast and reported to be rich in ethane and other NGLs. Better returns from extracting and marketing liquids could provide an added incentive for shale investment beyond profits arising from the thermal value of natural gas from shale deposits (ACC, 2011).

In addition to the fact that natural gas producers are focusing on drilling in NGL rich regions in order to improve their profitability, transportation of natural gas through pipelines requires that natural gas composition follows some specifications like NGL maximum content. So pre-treatment of natural gas becomes indeed necessary and makes available NGLs streams which are more valuable for petrochemical use than as a common fuel.

In 2010, the U.S. Gulf Coast cost position improved so much that the region now is second only to the Middle East in terms of competitiveness and as a result, for example, U.S. plastic exports are up nearly 10% due to this improved position (ACC, 2011). Furthermore, some analysts point out that ethane supplies are tightening and are constrained in the Middle East due to increasing electricity domestic demand and difficulties to develop non-associated gas production in some countries of the region (POTTER, 2010). The era of low-cost feedstocks seems to be challenged to continue for the next years for some producing nations in that region. This will also aid U.S. competitiveness and may induce capital investment in the United States (ACC, 2011; SANTOS et al., 2011; ZINGER, 2008).

Also, as a result of their confidence in an extended period of low natural gas prices, chemicals producers have already signaled their intentions to increase capacity in the U.S. Several companies have begun incremental expansions of their existing assets (Royal Dutch Shell, The Williams Companies, LyondellBasell, and Westlake Chemical), made and announced new investments (Dow Chemical), and others have announced major capital investment plans for the future (Chevron Phillips and ExxonMobil) (IHS, 2011; SANTOS et al., 2011). Most of these U.S. plans include provisions to export significant amounts of ethylene or ethylene derivatives, because of the expectation that their natural gas-based production will be cost competitive with oil-based production (IHS, 2011).

The debate over the petrochemical industry expansion in the United States is promoting a series of reports and government initiatives to attract investments in their states, and consequently, creating new jobs. For instance, the ACC report (ACC, 2011) presents the results of the analysis conducted to quantify the economic impact of the additional production of petrochemicals and downstream chemical products stimulated by an increase in ethane availability. ACC analyzed the impact of a hypothetical, but realistic 25 percent increase in ethane supply on growth in the petrochemical sector. It found that the increase would generate:

• 17,000 new knowledge-intensive, high-paying jobs in the U.S. chemical industry

• 395,000 additional jobs outside the chemical industry (165,000 jobs in other industries that are related to the increase in U.S. chemical production and 230,000 jobs from new capital investment by the chemical industry)

• US$4.4 billion more in federal, state, and local tax revenue, annually ($43.9 billion over 10 years)

• A US$32.8 billion increase in U.S. chemical production

• US$16.2 billion in capital investment by the chemical industry to build new petrochemical and derivatives capacity

• US$132.4 billion in U.S. economic output ($83.4 billion related to increased chemical production (including additional supplier and induced impacts) plus US$49.0 billion related to capital investment by the U.S. chemical industry) (ACC, 2011).

It is worth mentioning that another possibility that could have an impact on the petrochemical industry is the development of smaller scale and/or scalable petrochemical plants. The venture capital fund of the state government of West Virginia, where part of the Marcellus Shale is located, settled a deal to invest in the study of the development of smaller scale petrochemical plants. These plants, if proved economically and technically viable, could benefit from an advantage of having access to the local ethane production, reducing infrastructure costs that would be necessary to gather a larger amount of ethane and transport it to an existing production facility, as most of these are located in the U.S. Gulf Coast and far from Marcellus.

Low natural gas prices have increased the profitability of domestic production of fertilisers, resulting in the restarting of some plants, for example the CF Industries Holdings Inc. (Terra) plant in Donaldsonville, Louisiana, the Pandora Methanol plant in Beaumont, Texas, and the LSB Industries Inc.'s plant in Woodward, Oklahoma (IHS, 2011). However, the expected returns on investment may not be high enough to justify new builds on the US Gulf Coast. But consulting company IHS suggests that there may be a few new plants built in North America strategically located in areas close to both crop production and shale gas deposits, taking advantage of savings in logistics cost to improve returns (IHS, 2011[redacted]

7. Final considerations

The prominent growth in unconventional gas production in the United States in the 2000s was able to reverse projections by analysts in the natural gas industry, in the issues of the growing LNG imports through to 2030, as well as of petrochemicals, when it was indicated that the country would be a net importer of polyethylenes in the short-term.

With the greater availability of natural gas for petrochemical feedstock and, at advantageous prices in relation to naphtha, the ethylene production in the United States gained a new impetus in the global market. Although the gas-based petrochemical production profile provides a smaller array of products, the fact that the majority of the petrochemical production can use this lower cost feedstock benefitted the segment as a whole. At the peak of natural gas prices in the half of 2008, allied to the strong petrochemical demand stimulated by world economic growth, the perspectives were that the country would show a growing deficit in the resins market in the short term.

Shale gas allowed for the cost reduction in ethylene production, which increased the competitiveness of the United States petrochemical industry compared to other producing regions, such as Western Europe, where the production is mostly based on naphtha. Also, the country was able to reduce the advantage that the petrochemicals produced in the Middle East have over the remaining regions, what also contributed to the success of the ethylene derivatives, mainly through polyethylene, polystyrene and polyvinyl chloride, exports.

Thus, the future growth of the petrochemical industry in the United States shows a dependency not only to the domestic market itself, but also to the world economy dynamics and the capacity thereof of absorbing or not the supply of petrochemicals of countries with surpluses, such as the United States itself and Saudi Arabia. As the ethylene business has a cyclical characteristic and happens at a world level, the investment cycles in new capacity in the petrochemical industry strongly impact the supply and demand balance and affect the profitability of this industry.

Furthermore, considering that the question of the maintenance of the competitiveness of the American petrochemical industry may be attributed to a factor “exogenous” to the petrochemical industry, the unfolding of the unconventional gas exploration activities in the country must be observed. In case there is a change in the regulation of the unconventional production, especially in what concerns stricter environmental restrictions to production practices, there is the possibility that this resource will not reach all present projected potential. In this situation, the sustainability of the competitiveness of the petrochemical industry on the United States would be under a strong risk.

Another point is the need for additional gathering, transport and processing infrastructure. The Marcellus and some other shale gas deposits are located outside the traditional natural gas supply infrastructure to access the shale gas (ACC, 2011). It can be thought that with the dynamism and critical knowledge that the segment has already achieved, midstream investments tend to be carried out in a rhythm compatible with supply growth, even with some constraints arriving from environmental issues.

Although fertiliser production is also based on natural gas as a feedstock, it cannot take advantage of the excess supply of gas liquids from shale deposits in the manner that ethylene and propylene production can. Nitrogen fertilisers production is mainly based on methane as the most important fraction of natural gas for their production. Therefore, the impact on fertiliser production in the United States will not be as significant as it is in ethylene and propylene derivatives. Consequently, although low-cost shale gas has had a positive impact on US fertiliser production, the impact is not expected to be as significant as for the other chemicals (IHS, 2011).

A final issue concerns the dissemination and the extension of unconventional natural gas production on other parts of the world. In this regard, if the expansion of the supply of this type of gas is successful, the competition in the international petrochemical market due to a new gas supply and demand balance would be intensified, what could have consequences in the United States market. However, the present outlook of unconventional gas points to the North American region as the one with greatest success in the exploration and production of this resource.

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