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Natural gas in Brazil's energy matrix: demand for 1995–2010 and usage factors

Elton Fernandes, Marcus Vinícius de A. Fonseca, Paulo Sergio R. Alonso*

Graduate Engineering Programs Coordination Unit, Rio de Janeiro Federal University (COPPE/UFRJ), Ilha do Fundão, Rio de Janeiro, Brazil

Abstract

This paper describes and analyzes the constraints hampering achievement of the 12% share planned for natural gas in Brazil's energy matrix by 2010, and advises policies for reaching that goal on the basis of forecasts and three probable scenarios for the development of the Brazilian economy. The 12% share goal was established in 1993 by the Ministry of Mines and Energy and confirmed in 2000, and is now in full development. The figures used to represent the estimates of natural gas demands in the three scenarios were obtained from the Integrated Energy Planning Model (MIPE—Modelo Integrado de Planejamento Energético), which is a technical and economic forecasting model developed by a group of researchers linked to the Energy Planning Program run by the Graduate Engineering Programs Coordination Unit at the Rio de Janeiro Federal University (COPPE-UFRJ) under the sponsorship of Petrobras (a Brazilian enterprise operating in the oil and gas segment) and Eletrobrás (a Brazilian enterprise in charge of electricity demand planning). The analysis of the constraints take place under the aegis of the objective proposed by the Brazilian Government. The authors suggest specific actions to be taken in four application areas of natural gas: industrial, electric power generation, domestic distribution and vehicular fleet conversions. All the actions proposed encourage the use of a fuel with low environmental impacts and high calorie power, replacing firewood and other polluting fuels and are evaluated relative to the impacts occurring in society, especially from the standpoint of social welfare in a developing country. The necessity of developing the goods and services infrastructure in the country to support the natural gas insertion in the Brazilian energy matrix is also addressed.

Keywords: Energy planning; Energy matrix; Natural gas; Technology management

1. Introduction

Recent studies by the planning bodies of the Ministry of Mines and Energy (MME) associated to the most probable scenarios for the growth of Brazilian industry for the period 1998–2010, clearly show the important role reserved for natural gas as an alternative, quick response to the growing demand for energy, which will be necessary for the viability of sustained development of the country.

The subject, of indisputable geopolitical and strategic importance, deserves its growing attention from the government, not only for the availability of the fuel in our production fields and for the incentives to increase its supply by importing, as well as by the appeal of the use of a fine fuel, which makes it the best solution, among the alternatives, to the commitment to increase energy supply and the necessary modernization of Brazilian industry.

In order to accomplish what was established by these studies, the Ministry re-affirmed, in the year 2000, through the National Energy Policy Council (CNPE—Conselho Nacional de Política Energética)[1] the strategic target for the reconfiguration of the Brazilian energy matrix, so that natural gas will be responsible for 12% of this matrix up to the year 2010 (Ministério das Minas e Energia e Comissão do Gás Natural, 1992). This target was previously established by the former Gas Commission of the MME in 1992. The actions for its achievement are now under development.

The governmental target has as the principal anchor for its viability, the implementation of innumerable projects for the use of natural gas, the most important of which are various thermoelectric power plants, the

*Corresponding author. Petroleo Brasileiro S.A., Petrobras. Av. Republica do Chile, 65 sala 601 R-CEP 20271-900, Centro, Rio de Janeiro, RJ, Brazil. Tel.: +55-21-2534-1650; fax: +55-21-2534-4248.

E-mail address: alonso@petrobras.com.br (P.S.R. Alonso).

[1] Senior entity related to the MME in charge for defining energy policies and guidelines in Brazil.

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introduction of natural gas as an industrial fuel, the expansion of the domestic supply networks and the use of natural gas to power vehicles. Taking into account that Brazil is a tropical country, applications in the commercial sector for the generation of air-conditioning from natural gas are also under consideration.

The principal reasons for the introduction of natural gas in the energy matrix are related to the exceptional supply of natural gas available in Brazil's neighboring countries such as Bolivia and Argentina (Rosa et al., 1995), from which the use of this supply was made possible by the completion of the 3150 km Bolivia–Brazil gas pipeline in the year 2000 (Passos, 1999).[2] The Brazilian own reserves now sums up to 7324.9 billions of cubic feet (Petrobras, 2003) most of which are associated gas located in deep waters at the sea. In order to take advantage of the Argentinean gas, the construction of various gas pipelines are being planned which would permit the implementation of an even more ambitious program known as the Mercosur Energy Integration (see Fig. 1) (Mercosur—Southern Cone Common Market). On the other hand, there is the construction of thermoelectric power plants as an alternative to the heavy investments required for the construction of hydroelectric power plants, which being far from the large urban centers in a country the size of Brazil, implies the construction of costly transmission systems which today is the principal limiting factor in the performance of the Brazilian electrical system.

Growing international pressure related to the solution of environmental questions, also favor the introduction of natural gas in the industrial sector as a substitute for fuels such as firewood, still much used in the northern and northeastern regions of Brazil (Santos et al., 2002).

This work has as its objective to analyze the constraints and the technical viability for reaching the strategic target proposed by the Federal Government, based on projections for consumption in three economic development scenarios for the period 1995–2010. These consumption projections were obtained from the results of an energy planning model known as MIPE—Modelo Integrado de Planejamento Energético (Tolmasquim et al., 1998b) developed by a team of researchers from the Energy Planning Program run by the Graduate Engineering Programs Coordination Unit at Rio de Janeiro Federal University (COPPE-UFRJ).[3] The principal existing constraints for the introduction of natural gas in four consumption sectors—energy generation, industrial, residential and automotive—are analyzed and measures are suggested by the authors to facilitate the attainment of the government's target. These segments are considered today as the main ones for concentrating strategies with the objective of the insertion of natural gas into the Brazilian energy matrix. The feasibility of the measures suggested is analyzed under the political, economical and social aspects as well as is emphasized the necessity of concrete actions to foster technological expertise and the growth of the goods and services industries in the country as to support the introduction of natural gas in those segments.

[2]The pipeline crosses all important Brazilian state capitals in the central-west and south regions including São Paulo. Its nominal capacity is 30 million Nm^3/day being used today at about 50% full capacity (see Fig. 1).

[3]In view of the need to obtain a tool able to produce demand forecasts for the different types of energy consumed all over the country, Brazil's state-run enterprise operating in the oil and gas segment, Petrobras, signed an agreement with COPPE-UFRJ covering the development of a system designed to prepare forecasts of Brazil's energy matrix (Fantine, 1997).

2. Energy demand planning in Brazil: historical framework

Energy demand planning has always been carried out in an unsatisfactory manner in Brazil due to the complete lack of a programming model and the shortage of reliable data reflecting the performance of the various energy-intensive industrial segments.

Only those sectors in which the state-owned companies were the majority some years ago provided data regularly regarding that energy demand and processes efficiencies. After the privatization process that occurred in recent years these data are no more available. Low oil prices in effect through to the early 1970s and the lack of international pressures urging environmental preservation also failed to encourage the development of this model or even a detailed study based on probable energy demand scenarios.

The crises that swept through the Brazilian economic scene during the 1980s, in parallel to the need to supplement domestic oil output with imports at around 60% of local demand, prompted Government agencies and state-run enterprises in the energy sector to seek solutions for preparing energy matrix forecasts and estimating product demands.

For Brazil's energy matrix as such, this topic was limited to the sphere of the MME, which started to infer the composition of this matrix on the basis of a consumption data survey covering the various energy sources and their applications (driving force, process heat, direct heating, lighting, etc.) for the most significant economic sectors.

Basically brought together in two annual reports: the National Energy Balance (BEN—Balanço Energético Nacional) and the Useful Energy Balance (BEU—Balanço de Energia Útil) (Ministério das Minas e Energia, 1998) these data were and are still used today to estimate the demand for a specific type of energy by the industrial sector in a given year. Based on the

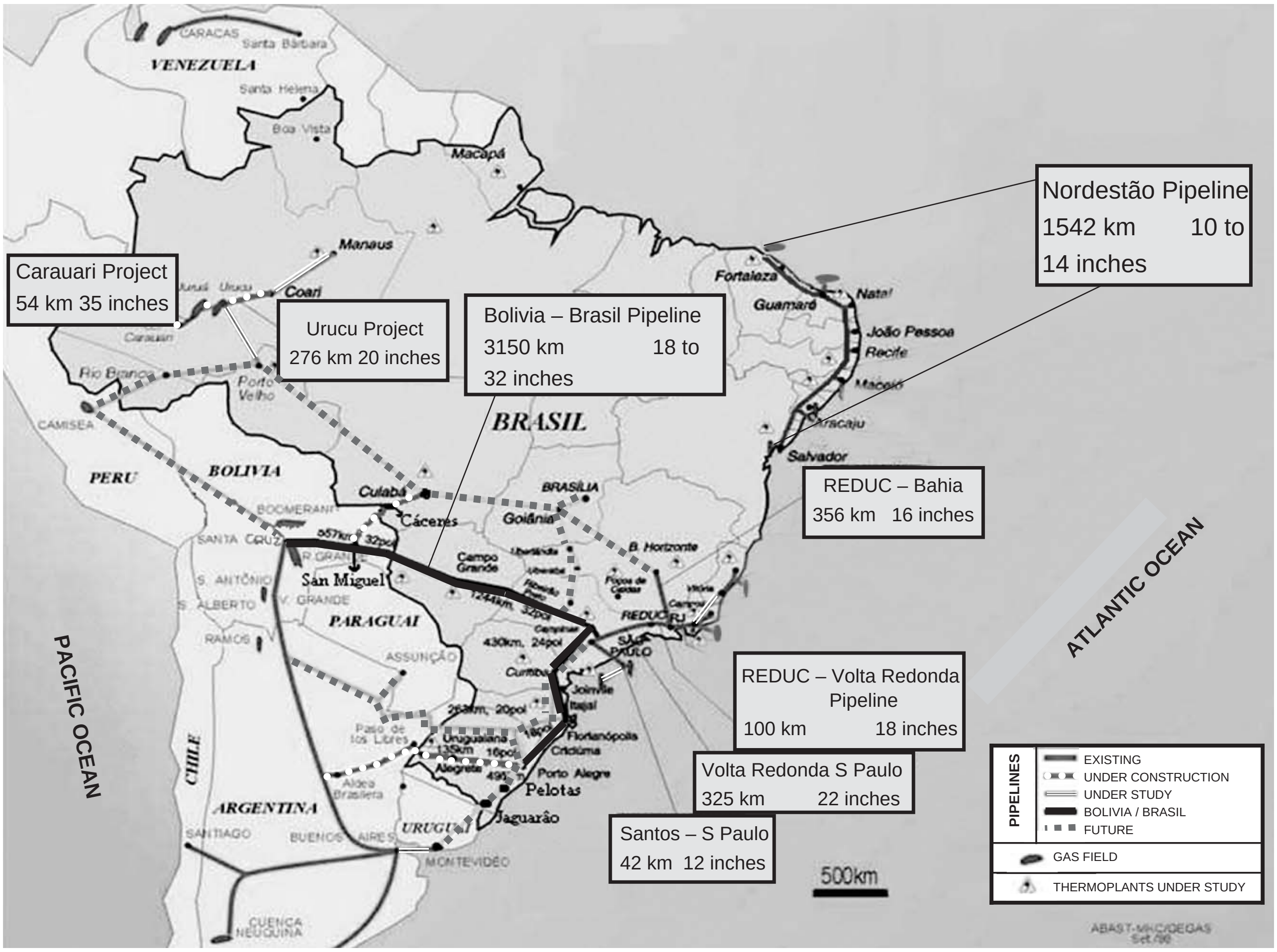


Fig. 1. Mercosur energy integration. *Source*: Petrobras Transportation Department.

historical data, it is possible to infer the composition of the energy matrix through a reasonable computer-based task.

In 1998, the design of MIPE was completed and the model was first run by the end of that year to evaluate the energy demand forecasts for the period 1998–2010 based on three economic scenarios. The results were published in Tolmasquim et al. (1998a) and in this article we use these results concerning the demand of natural gas to analyze the main constraints that impact the feasibility of achieving the strategic Government target of reaching a 12% share for natural gas in Brazil's energy matrix by 2010. The analysis is carried out taking into account the multiple changes that occurred in the Brazilian economic scenario from 1999 to the present days. For the period running from 1995 to 1998, real demand data were used, drawn from the BEN.

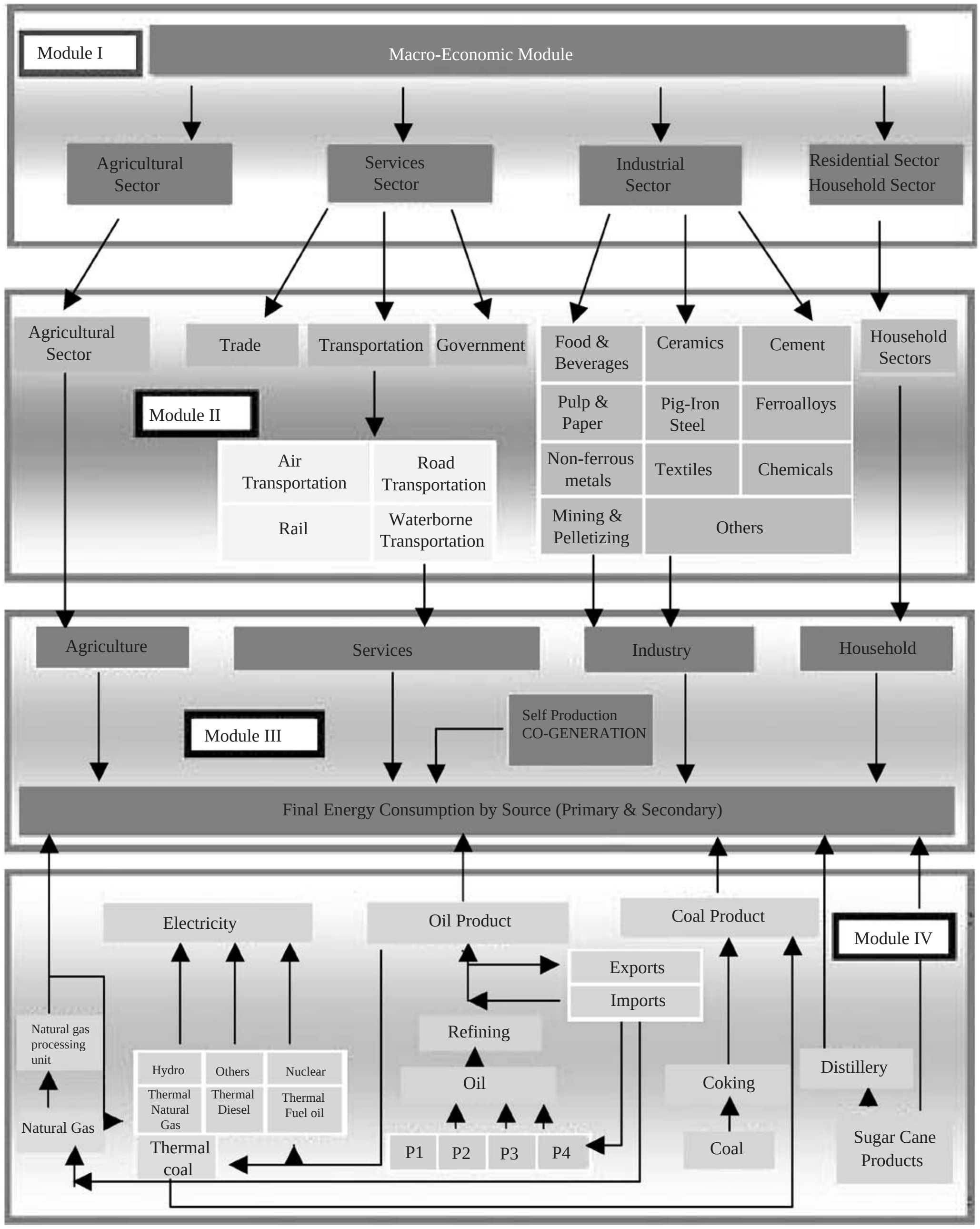
3. Integrated Energy Planning Model (MIPE)

Tolmasquim et al. (1998a) describe the MIPE as a "technical and economic forecasting mechanism that schematizes the energy demands and supplies available in Brazil, in order to simulate widely diversified scenarios for each energy supply and consumption segment. It consists of four modules: Macro-Economic Module, Energy Demand Module, End-Consumption Module and Supply Module".

3.1. Sectors studied

The application of MIPE considers the consumption of energy in the industrial, residential, farming and services sectors. For the Industrial Sector, specifically, it followed the basic division of the BEN, namely: Food and Beverages, Cement, Ceramics, Pig Iron and Steel, Cast Iron, Mining/Pelletizing, Chemicals, Non-Ferrous and other Metals, Textiles, Paper and Cellulose and, finally, Other Industries. The service sector is sub-divided into Commercial, Public and Transport.

For our work, the results relating to the demand for natural gas by the sectors considered will be the focus of our attention.



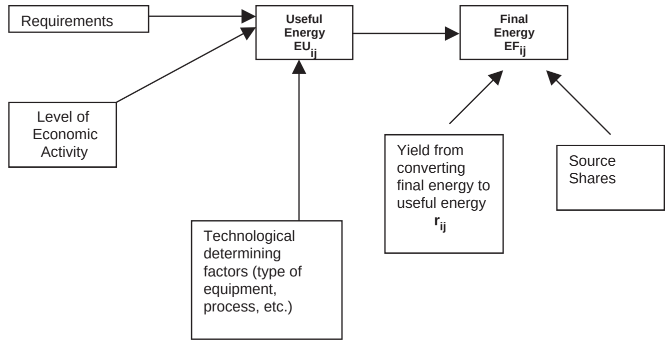
Module I - Macroeconomic Module; Module II - Energy Demand Module;
Module III - Final Consumption Module; Module IV - Supply Module;

Fig. 2. General structure: Integrated Energy Planning Model (MIPE). *Source*: Tolmasquim et al. (1998a).

3.2. General structure and grounds for the model

We reproduce in Fig. 2 the MIPE's general structure, defining the conceptual functions of the four modules that constitute the model: module 1 is the Macroeconomic Module defining scenario variables and product distribution among demand sectors; module 2 is the Energy Demand Module defining analysis variables for each segment in each sector, in order to obtain the useful and final energy demands; module 3 is the Final Energy Consumption Module clustering the results of the module 2 and the energy consumption results for the energy sector given in module 4, obtaining the final energy required by the consumption sectors; module 4 is the Supply Module that defines the energy supply analysis variables, obtaining both the quantities of primary and secondary energy supplied, as well as the energy consumed by the power sector.

In the results provided by the MIPE, primary supply of natural gas, gas products and oil derivatives is based on Petrobras projections (the only Brazilian enterprise operating in the oil and gas sector) taking into account



Eu = Useful energy; energy that meets a necessary demand (heat generation for instance) and performs an economic activity (production of goods and services) within a certain physical and technological context (climate, production, process. It is independent of energy sources used;
Ef = Final energy; energy that depends on the energy sources used and conversion yelds.

$\mathbf{Eu_j}$ = Useful energy by type of use, depending on the type of equipment and process used;
$\mathbf{Eu_{ij}}$ = Useful energy by type of use by energy source; for instance, the amount of process heat required that is generated through burning fuel oil in a boiler. Thus, $Eu_{ij} = Eu_j$x share held by source i;
$\mathbf{r_{ij}}$ = Conversion yield by type of use by energy source; for instance, the yield of a boiler consuming fuel oil;
$\mathbf{Ef_{ij}}$ = This is the final energy by type of use by energy source, for instance, the amount of fuel oil consumed by a boiler for a given amount of heat . Thus: $\mathbf{Ef_{ij} = Eu_{ij} / r_{ij}}$

Fig. 3. Concept definition: useful energy and final energy. *Source*: Tolmasquim et al. (1998a).

the natural gas fractions that are re-injected in production wells and the fraction piped to the natural gas processing plants.

The Demand Module constitutes the heart of the model, mixing the impact factors from the macro-economic scenarios and technical issues from the different consumption sectors. Based on this module and the energy supply options in the Supply Module, the forecast is drawn up.

The general structure of the model is based on three basic conceptual procedures:

- Transfer the impact of the variables on the macro-economic scenarios, for each sector considered, in terms of useful energy demand and final energy demand.
- Analysis of energy demand by method of use in each consumption sector.
- Establishment of the demand for useful energy, the efficiency of the conversion of useful energy into final energy and the determination of the final energy, for each method and use of energy. This implies a knowledge of the most widely used production processes in each consumption sector of industry.

Again according to Tolmasquim et al. (1998a), "this Model explicitly considers the factors that directly determine demand: for instance, the final energy demand is based on the energy consumption requirements of a specific item of equipment or processing device (boiler, furnace, engine…) with a known yield. The energy requirements are precisely the useful energy that meets a necessary demand (heat generation, for instance) and performs an economic activity (production of goods and services) within a certain physical and technological context (climate, production process…). It is this useful energy that is directly related to production which is independent of the energy sources used. In turn, the final energy depends on the energy sources and the conversion yields. This means that energy is defined through type of use, together with the shares held by the various sources and their yields, giving the final energy figures". Fig. 3 illustrates the concepts mentioned above.

When broken down by source, the results of the final energy demand and supply analysis allow the model to characterize production sector consumption modes, as well as forecasting energy supplies by source and technological alternatives.

3.3. Scenarios used

When obtaining the energy matrixes through the Integrated Energy Planning Model (MIPE), three development scenarios were taken under consideration. Scenarios 1 and 2 analyze the Brazilian energy market for 1998–2010, based on the analyses carried out by Brazil's National Social and Economic Development Bank (BNDES) and the Applied Economics Research Institute (IPEA) in 1997 (Além, 1997). Scenario 3 is based on the assessments by researchers from various units at the Rio de Janeiro Federal University (UFRJ).

The three macro-economic scenarios taken under consideration may be described in general lines as follows:

Scenario 1—low growth. It is based on the External Constraints Scenario in the 1997 BNDES study that assumes moderate GDP growth and a trend towards the development of the economic structure, with no shocks, crises or significant alterations.

Table 1
Qualitative summary of the scenarios

	Scenario 1: low growth	Scenario 2: high growth	Scenario 3: sustainable development
General comments	Based on the external constraints scenario—BNDES	Based on the IPEA scenario (1997)	Regulatory—prepared by the working group
GDP growth rate adopted for 1997/1998/1999 (repercussion of international financial crisis in 1997)[a]	3.2% p.a.[b]/1.5% p.a./3.2% p.a.	3.2% p.a./1.5% p.a./3.2% p.a.	3.2% p.a./1.5% p.a./3.2% p.a.
GDP growth rates adopted from 2000 onwards	3.8% p.a.	5.6% p.a.—does not rise evenly during the period under analysis. From 2000 to 2002, the GDP rises more slowly, reflecting the need for lead-time in order to adapt to the adjustments such as increased domestic savings, building up the skills of Brazilian workers; upgrading the infrastructure.	5.6% p.a.
Basic assumptions	Ongoing balance of foreign accounts; lower investment levels in manufactured products with higher added value; moderate increase in exports of non-factor goods and products, with rising trade deficits and current account shortfalls, curtailing GDP growth.	Promotion of sustained long-term growth, adjustment of public accounts (pre-condition) and better living conditions for the Brazilian populace. Faster reform of the Government sector in order to foster economic growth and redirect the state towards new functions—the Entrepreneur State becomes the Regulator State and provider of social services, also concentrating on preserving economic stability.	The forecast includes some parameters and hypotheses that were either not taken under consideration in earlier Scenarios or were dealt with implicitly. Matters linked to distribution are handled more strictly and objectively, rather than as a natural consequence of economic growth itself; the privatization process is not broken down, and although some of the duties and responsibilities of the State have been pruned away, it still maintains some areas rated as strategic. On the other hand, the regulatory role of the State in the economy has expanded.
Bases for growth	Moderate growth for investments and exports, guided by the foreign market.	Investments and exports (considerable growth), gains in competitiveness (driven by the international market) production focused on exports, redefining the competition standards of industry. The success of this upsurge "depends on the steady development of the global economy, as substantial amounts of foreign funding are required, both risk capital and loans as well as for financing shortfalls in current transactions at around 4% of the GDP for a few years".	Investments, exports, encouragement for products with higher added value, gains in efficiency and a keener competitive edge, energy savings and supply-side management in addition to replacing equipment performing poorly for converting final energy into useful energy, as well as the substitution of energy sources shaped by technical, economic and environmental criteria. The export rate rises, but is subordinate to national interests defined by sectoral development policies.
Investment	Lower investment expansion—less need for savings. Government funding rises slightly faster than private investment: public accounts improve and foreign savings increase to a lesser extent.		Financing the shortfall in current transactions with the flow of current capital generates a weak point that is of much concern. This scenario feels that investment effectively helps to expand the production capacity of the economy and bring in

Table 1 (*continued*)

	Scenario 1: low growth	Scenario 2: high growth	Scenario 3: sustainable development
General comments	Based on the external constraints scenario—BNDES	Based on the IPEA scenario (1997)	Regulatory—prepared by the working group
			technologies, particularly in sectors generating foreign exchange earnings, through either exports or export substitution; consequently, sector development policies are crucial for economic deregulation.
Population concentration	Follow Scenario 2	Population concentration in urban areas, particularly major cities, should continue although at a slower pace. This scenario foresees a negative variation in the rural population growth rate of −0.7% from 1995 to 2000, while the urban population will tend to increase at a rate of 1.8% p.a. from 1995 to 2000, and 1.6% p.a. from 2000 to 2005.	Speeding up the agrarian reform process with investments in rural infrastructure, helping workers settle on the land; incentives to set up agricultural hubs and rural cooperatives in order to generate small-scale centers of economic activity in rural areas; development of energy generation projects based on biomass sized to meet the demands of rural settlements that still lack electricity. The growth rate for the rural population represents firmer settlement of workers in rural areas, reaching 0.5% p.a. for 1995 –2000, and −0.2% p.a. on average for the remaining period running from 2000 to 2010.
Demographic growth rates[c]	Follow the rate forecast in Scenario 2	This rate hovers around 1.3% p.a. during the 5 years between 1995 and 2000, dropping to 1.2% p.a. from 2000 to 2005, which is in keeping with the previous scenario prepared by the BNDES—and 0.6% p.a. from 2015 to 2020.	According to the profile described in Scenario 2, with lower mortality rates through significant investments in the fields of sanitation, healthcare and housing.

[a] The actual rates posted for 1997, 1998, 1999 and 2000, respectively, were: 3.3%, 0.8%, 0.8% and 4.4%. *Source*: IPEA.
[b] P.a. means per annum.
[c] The real demographic growth rate noted for 1995–2000 was 1.35% p.a. *Source*: IBGE.

Scenario 2—high growth. It is based on the projections drawn up by the Institute of Applied Economic Research (IPEA) in 1997 (Além, 1997), with high GDP growth and dynamic economic development underpinning this expansion.

Scenario 3—sustainable growth. It uses the same growth projection as the previous scenario, but introduces significant alterations in the energy demand and supply structure, denoting an alternative development model.

It is worthwhile stressing that the scenarios adopt the same growth rates as the BNDES and IPEA for 1997–2002, despite a 3-year lag in terms of the original validity period of the scenarios. This means that the rates estimated for 1997, 1998 and 1999 were actually used for 2000, 2001 and 2002, respectively. According to Tolmasquim et al. (1998a) "this procedure was based on the financial crisis triggered by the collapse of the Asian markets in late 1997, whose international repercussions caused a worldwide recession". Table 1 summarizes the main characteristics of the scenarios under consideration.

4. Results obtained with the Integrated Energy Planning Model (MIPE)

We will now analyze the MIPE's results obtained for the energy demand forecasts in Brazil for 1995–2010 as published in 1998 and focus our analysis in the prospects for natural gas. The results cover energy consumption by industrial sectors (Food and Beverages, Cement, Ceramics, Pig Iron and Steel, Ferroalloys, Mining/Pelletizing, Chemicals, Non-Ferrous and Others/Metallurgy, Textiles, Pulp and Paper and finally other industries) as well as household, agricultural and services (commerce, government and transportation).

Real energy source demand data were used for 1995–1998, published in the BEN issued by the MME, as well as other sources of information. For other years, estimates were based on historical statistics and consumption projections based on the Scenarios studied.

In order to examine and focus the share and the role of natural gas in the Brazilian energy matrix, three sets of tables were derived, one for each scenario considered. These sets of tables were then grouped together in one comprising three tables (Tables 2–4) to make the comparisons clearer for the reader.[4]

When consolidating the results, we also grouped sources deriving from the same origin, which made it easier to visualize the matrix and analyze the shares held by these energy sources more clearly. Consequently, steam coal, metallurgical coal, coke and charcoal were classified only as coal, with their shares in the matrix added together; similarly, diesel oil, gasoline, fuel oil, LPG, kerosene and fuel gas were treated in the same way, clustered under the oil products group. Sugar cane, alcohol, fuel wood and others were kept separate as they do not fall under any energy source headings.

4.1. Natural gas demand and energy matrix for Scenario 1

The natural gas demands as compared to other sources are presented in Table 2 for all three scenarios. Concerning Scenario 1 it is important to point out the assumed lowest growth rates in the economy and the absence of significant technological innovations in terms of either products or processes for this scenario as shown in the qualitative summary (Table 1). The assumptions are valid for all the energy consumption sectors of the Brazilian energy system during the period covered by the forecast.

Total energy consumption rises 64%, while the GDP increases by around 70%. The difference between these two figures may be assigned to certain gains in energy efficiency, although not comparable to those in the other two scenarios and occurring mainly in the residential sector, as well as the steel and chemical industries, in addition to food and beverages.

We see that the natural gas market rises from 2,208,000 tep in 1995 to 11,880,000 tep in 2010.

Electricity holds the highest share, at over 40% of total energy demands. This consumption is due mainly to the industrial sector with around 50% of total

[4] For more details the reader is referred to Alonso (1999).

Table 2
Brazil's energy matrix in three scenarios (tep × 1000)[a] 1995–2010

Source	Scenario 1: low growth						Scenario 2: high growth						Scenario 3: sustainable development					
	1995	% Share	2003	% Share	2010	% Share	1995	% Share	2003	% Share	2010	% Share	1995	% Share	2003	% Share	2010	% Share
Natural gas	2207.80	1.26	6359.90	2.77	11,879.80	4.14	2207.80	1.26	7318.50	3.04	17,125.40	4.82	2207.80	1.26	7551.90	3.20	17,831.80	5.24
Coal[b]	12,866.80	7.36	16,597.90	7.22	19,868.70	6.92	12,866.70	7.36	17,234.70	7.15	25,674.20	7.23	12,866.70	7.36	16,713.00	7.08	23,631.10	6.94
Oil products[c]	53,841.00	30.80	76,150.30	33.12	94,444.10	32.91	53,841.00	30.80	78,261.30	32.48	114,838.80	32.34	53,841.00	30.80	75,661.30	32.03	106,698.60	31.34
Sugar cane	7312.50	4.18	8963.40	3.90	11,730.00	4.09	7312.50	4.18	9432.30	3.91	15,356.70	4.32	7312.50	4.18	9618.60	4.07	16,172.40	4.75
Fuelwood	13,053.20	7.47	14,768.00	6.42	15,912.90	5.54	13,053.20	7.47	14,911.40	6.19	17,969.50	5.06	13,053.20	7.47	14,915.00	6.31	17,531.30	5.15
Electricity	74,660.90	42.71	98,131.30	42.68	122,683.90	42.75	74,660.90	42.71	104,674.50	43.44	151,413.10	42.64	74,660.90	42.71	102,041.00	43.20	145,952.60	42.87
Alcohol	7270.70	4.16	4627.40	2.01	5138.60	1.79	7270.70	4.16	4702.30	1.95	6506.80	1.83	7270.70	4.16	5312.00	2.25	6508.00	1.91
Others	3593.90	2.06	4350.60	1.89	5331.80	1.86	3593.90	2.06	4434.40	1.84	6220.10	**1.75**	3593.90	2.06	4373.10	1.85	6103.80	1.79
Total	174,806.80	100.00	229,948.80	100.00	286,989.80	100.00	174,806.70	100.00	240,969.40	100.00	355,104.60	100.00	174,806.70	100.00	236,185.90	100.00	340,429.60	100.00

Source: Tolmasquim et al. (1998a).
[a] Tep = tons equivalent petroleum.
[b] Includes steam coal, metallurgical coal, coke and charcoal.
[c] Includes diesel oil, gasoline, fuel oil, LPG, kerosene and fuel gas.

Table 3
Average growth rates for natural gas and total energy in three scenarios (tep × 1000)[a]

Year	Scenario 1: low growth						Scenario 2: high growth						Scenario 3: sustainable development					
	Gas	% Delta	Average % delta	Total energy	% Delta	Average % delta	Gas	% Delta	Average % delta	Total energy	% Delta	Average % delta	Gas	% Delta	Average % delta	Total energy	% Delta	Average % delta
1995	2207.80			174,807.00			2207.80			174,807.00			2207.80			174,807.00		
1998	2775.90	7.92		194,405.60	3.60		2808.30	8.34		195,690.80	3.83		2868.50	9.11		194,310.00	3.58	
2000	3099.60	5.67		208,027.60	3.44		3794.90	16.25		210,427.10	3.70		3252.30	6.48		207,915.00	3.44	
2003	6359.90	27.04		229,948.80	3.39		7318.50	24.45	**14.30**	240,969.40	4.62		7551.90	32.38		236,186.00	4.34	
2006	8290.70	9.23	**11.45**	251,487.80	3.03	**3.36**	11,864.30	17.45		281,345.70	5.29	**4.90**	11,538.50	15.16	**14.36**	271,383.00	4.73	**4.63**
2008	9618.30	7.71		268,235.20	3.28		15,042.10	12.60		316,567.80	6.08		13,900.20	9.76		303,408.00	5.74	
2010	11,879.80	11.14		286,989.80	3.44		17,125.40	6.70		355,104.60	5.91		17,831.80	13.26		340,430.00	5.93	

[a] Tons equivalent petroleum.

demand, followed by the residential sector at 25%. The demand for oil products consists mainly of diesel oil and gasoline at around 20% of total energy demands, due to the profile of Brazil's transportation sector, which is largely road-based.

The expansion of the share held by natural gas in Brazil's Energy Matrix can be noted. Within the time frame of the projection, from 1995 to 2010, natural gas rises from 1.2% to 4.14%, but in absolute terms the demand rises by more than 400%, at an annual growth rate of 11.45% over the period under consideration (see Table 3). However, even with the significant participation of the thermopower segment, this figure is still well below the 12% strategic target set by the Government. Over the timeframe under consideration, the share held by electricity barely varies.

4.2. Natural gas demand and energy matrix for Scenario 2

The Energy Matrix for Scenario 2 and the natural gas demand reflect the assumptions presented in Table 1 for this scenario, facing the highest economic growth rates and significant technological innovations when compared to the other scenarios.

The total energy consumption rises by around 103%. This consumption is approximately 24% higher than the total energy consumption for Scenario 1, prompted by the higher economic growth built into Scenario 2, requiring higher energy consumption in order to drive this growth.

The penetration of natural gas in the demand projections for the energy consumption sectors is quite clear, with its share rising from 1.2% to 4.8%. Its consumption rises 675% from 1995 to 2010, at an average annual rate of 14.30% (see Table 3) even higher than Scenario 1.

This increase is leveraged by the presence of the thermopower plants and the substitution of other energy sources. Although its share in Brazil's energy matrix in 2010 is only 4.82%, this figure shows marked improvement compared to the 1.26% share held in 1995.

4.3. Natural gas demand and energy matrix for Scenario 3

In this scenario, the GDP growth rate is the same as in Scenario 2. There are technological changes involved, especially considering pollutive energy sources and industrial processes that are replaced by cleaner and more efficient alternatives.

Total energy consumption rises 95% while the GDP expands the same 109% as in the previous scenario. The energy consumption is lower than Scenario 2 due to the technological innovations introduced both in products and processes mainly in the industrial sector, posting the highest gains in efficiency among all the scenarios.

Table 4
Elasticity consumption/GDP for the scenarios considered

Source	Scenario 1	Scenario 2	Scenario 3
Natural gas	6.267	6.206	6.206
Electricity	0.920	0.944	0.944
Oil products	1.070	1.040	1.040
Fuel wood	0.313	0.346	0.346
Total	0.918	0.947	0.947

Another factor is the inclusion of co-generation in some sectors such as Chemicals, as well as Food and Beverages.

The figures show that natural gas share in the matrix rises from 1.2% to 5.2%, demonstrating the expected boost in consumption. Natural gas is rated as a clean and efficient source of energy, a good solution for the replacement of fuel oil and wood in industrial furnaces for instance. Nevertheless, its usage will depend strongly on a cultural change from the side of entrepreneurs and on the building of a product and services structure in the country to support the applications in the energy consumption sectors.

The annual average growth rate for natural gas is the highest of the three scenarios under consideration (again, see Table 3). Society is more keenly aware of the environmental aspects that favor natural gas, as it is a cleaner and more efficient source of energy that results in its being selected instead of other energy sources. Nevertheless, its share in Brazil's energy matrix reaches only 5.24%, indicating that the target established by the Government may be too ambitious.

4.4. Natural gas in thermopower plants

Table 2 includes natural gas demands from the thermopower plants, although under some analyses this demand may be rated more as an energy supply. In our view, we feel that in fact this demand consists of an *energy transformation*, and this is the manner in which it is considered in the BEN. However, in order to check the percentage of natural gas usage in the Energy Balance, this demand should be taken under consideration, particularly because it was the expected expansion of the power generation market that prompted the MME to establish the strategic target currently under analysis.

The consumption of natural gas for thermopower plants as forecast in 1998 was indeed very high from 2003 onwards[5] underpinned by rising imports shipped mainly by the Bolivia–Brazil Gas Pipeline. All three scenarios considered the opportunities envisioned at the time for the introduction of those plants in the Brazilian electrical sector. Today the real situation is quite different as we will discuss later, due primarily to the difficulties faced in attracting foreign investors to fund the projects. The role of thermoelectricity in Brazil is currently being revised by the Government and we expect new policy directions to be issued by the end of 2003.

[5] Regarding the natural gas total demand for 2010 as forecast by the Model, the thermopower sector would respond for 66% of that demand in Scenario 1, 67.2% in Scenario 2 and 61.4% in Scenario 3 (Tolmasquim et al., 1998a).

4.5. The relation elasticity consumption/GDP in the three scenarios

It is interesting to discuss briefly the elasticity consumption/GDP for the main energetic sources in the three scenarios studied. From Table 4 we can see that for all the scenarios studied the figures for natural gas are relevant, representing the entry of gas in the Brazilian energy matrix. The index for electricity is lower than unity in all three scenarios, denoting an efficiency gain in industrial processes in some economic sectors especially in the case of Scenario 3. The fuel wood shows the least elasticities in all three scenarios which denotes a declining trend in the usage of this energy source in Brazil. As for the oil products the elasticity in Scenario 3 is bigger than in the other scenarios, fostered by diesel oil denoting an increasing trend in the usage of buses in major cities and capitals. The lower elasticity for the total energy in Scenario 3 when compared to Scenario 2, is mainly due to the gain efficiencies mentioned before.

5. Government targets: main restrictions and actions required to meet the goals

Based on the results achieved through the use of the Integrated Energy Planning Model (MIPE) and taking into account the three development scenarios under consideration, we analyze below the obstacles blocking the Government target of reaching 2010 with a 12% share held by natural gas in Brazil's energy matrix. The analysis addresses the four main sectors to focus in fostering the consumption of natural gas in Brazil as mentioned in the Introduction: thermopower plants, industrial applications, urban domestic gas and vehicle conversions. Those, in our point of view, are also the sectors with the most significant social and environmental impacts in Brazil's future regarding natural gas usage.

5.1. The target in its essence

In reality, when established by the Natural Gas Commission of the MME in 1992, the proposed 12% target for the participation of natural gas in the energy matrix in 2010, was a number considered possible in view of the energy consumption registered for all the productive sectors by the National Energy Balance, the prospect of gas supplies from Bolivia via the Bolivia–Brazil gas pipeline and the potential for substituting other energy sources with harmful environmental effects such as firewood, sugar cane and fuel oil. Naturally, to make this expectation viable, a clear definition was necessary of the policy on pricing to supply natural gas on a competitive basis, in relation to other energy sources (Ministério da Fazenda e Ministério das Minas e Energia, 2000, 2002). Up to now this policy has not been fully established and requires clearer definitions and understanding between the Regulatory Agency for the Oil and Gas Sector—ANP—(linked to the MME), the Industrial Federations, the distributing companies and the potential consumers (Presidência da República, Ministério das Minas e Energia, 1997).[6] Moreover, a number of other issues (see discussion in Section 5.2.2) need better and clearer definitions, especially the funding mechanisms to support the huge investment projects that will be necessary in the thermopower plants and in the construction of a large pipeline distribution network throughout the country.

5.2. Thermoelectric power plants

5.2.1. Characteristics of the Brazilian electricity sector

Brazil is a country with unique characteristics in respect to electricity generation. More than 95% of the energy generated in the country is based on hydroelectricity, generated in large hydroelectric plants (Rosa and Tolmasquim, 1998). This means the national supply depends on a regime of the probability of rainfall, based on the climatic characteristics in the diverse regions of Brazil. However, the forecasts can fail due to the great variation in the world's climate which reflects on the rainfall in Brazil.

Due to the large scale supply of Bolivian gas and in order to complement the base generation of hydroelectricity in the country and to lessen the uncertainty of the current supply model, in 2000 the Priority Program for Thermoelectricity (PPT) (Ministério das Minas e Energia, 2000) was instituted, the objective of which was to construct thermoelectric power plants in areas where the gap between electricity supply and demand was accentuated. The thermoelectric power plants have some advantages over the hydroelectric plants of same capacity namely a much shorter construction time and the possibility of siting them close to large consumption centers, without the need for heavy investment in long transmission lines.

The Priority Program for Thermoelectricity forecast the construction of 49 electricity generating plants, the majority using natural gas as the fuel (Gazeta Mercantil, 2000). The total estimated investment for the Program was about US$ 4 billion (Veríssimo, 2000). These plants are large consumers of natural gas with a base of 1,000,000 Nm^3/day[7] for each 230 MW of power generated by combined cycle (for open cycle generators the consumption is in the order of 1,000,000 Nm^3/day for each 150 MW of power generated). Companies interested in the use of cogeneration also make up a large market for the supply of new energy. These thermoelectric power plants, as they are large consumers of gas, should act as anchors, causing a notable alteration to the energy matrix of the country, which is predominantly hydroelectric.

5.2.2. Difficulties to implement PPT

Specifically in the case of the PPT, other obstacles hinder the development of the program, amongst which we can highlight:

- *Natural gas tariff*

  Some agents and private entrepreneurs state that the pricing for natural gas is high, preventing a return on the investments made. Today, for the generation of thermoelectricity the stipulated price is around US$ 2.58 per million BTUs (Ministério da Fazenda, Ministério das Minas e Energia, 2002) at the city-gates (the point where the large gas carrier delivers the fuel to the local state distributor). This cost, applied to thermoelectric power plants planned to operate in Brazil as combined cycle generators, takes the final selling price for the energy produced to the range of US$ 38 to US$42/MWh. Although these prices are within the international average for the production of thermoelectricity, they are very high for a country where hydroelectricity is at the level of US$ 14 to US$ 17/MWh. For single cycle the final price for thermoelectricity is even higher at around US$ 60.00/MWh.

  These values cover the costs of fuel (natural gas), operation and maintenance and of investment (return on capital invested). This price when converted to real, the Brazilian currency, varies, reflecting day to day exchange rates. Nevertheless, the gas price may have a fixed dollar value to return foreign investments in the settling of the power plants, provided that a huge portion of pieces of equipment (gas turbines and generators) are purchased abroad. Moreover the energy price in reals may vary without

[6] In Brazil, the maximum price allowed for the commercialization of Natural Gas is established by the Ministry of Mines and Energy taking into account the evaluation of the Regulatory Agency, the Federation of Industries, distribution companies (mainly Petrobras) and potential consumers.

[7] Nm^3 means 1 m^3 of gas in standard measurement conditions namely 1 atm pressure @ 60 °F temperature.

control in the presence of monetary waves that normally affect developing countries as a reflex of global economic moods. These variations would be difficult to absorb over the long term if assumed by the investors (Jabur, 1999; Jabur and Santiago, 2000). The contracts for buying and selling energy are long term and vary between 5 and 10 years with prices calculated in reals (Brazilian currency). All of these variables and others that we discuss later still impede the outlook for the MWh, from the thermoelectric power plants, to be sold in the country.

- *Constitution of consortia*

  Difficulties in the constitution of consortia for the construction and operation of power plants, formed in accordance with the project finance model, without government resources is also of main concern (Gasparini, 1999a).

  These consortia have to comply with the interests of four agents: the natural gas supplier, the power plant operator, the supplier of the principal equipment and the financing bank. In a country with an unstable economy such as Brazil, where the value of the currency can fluctuate significantly each day in relation to the dollar, it is extremely difficult to reconcile the interests of the parties and the return on the capital invested (Brealey and Habib, 1996). To aggravate the problem further, Brazilian tax legislation is complex and frightens foreign investors who end up opting for other forms of investment where they can foresee a quicker return for their efforts.
- *Difficulties in obtaining environmental licenses*

  This is the case in the Southern States and, in particular, São Paulo, where NGOs (Non-Governmental Organizations) are mobilized. The use of water and emissions of contaminants into the atmosphere are rejected by a section of organized society, which in the past few years is ever more aware of the environmental risks and the preservation of the quality of life. Social responsibility and the promise of clean and safe operations are today a firmly required pre-requisite from companies and investors.
- *Power purchase agreements—PPA's contracts*

  For energy sales there is a necessity of establishing bi-lateral long-term contracts known as PPAs. The principal difficulty lies in the fact that in Brazil the supply of electricity to the consumption centers is made in a centralized manner by a body known as the National System Operator (ONS—Operador Nacional do Sistema) which, obviously, is interested in supplying the cheapest electricity to the consumers. All of the electricity distribution concessionaires, because of their initial contracts, had guaranteed the supply to their markets, forecast up to 2002 with the generators, only requiring new contracts or renegotiation of existing contracts from 2003 on. The obligatory renegotiation of the energy contracts was suspended by the Government, and hydroelectricity continues to be offered to the distributors by the ONS at very attractive prices, as the large hydroelectric plants are totally amortized.
- *High taxation on the entire production cycle and sale of electricity*

  The Brazilian tax structure is heavy and complex. In the first quarter of 2003 total taxation reached US$48 billion or 41.23% of total GDP for that period (O Dia, 2003). For the construction of thermoelectric power plants there are taxes payable at the following points in the cycle: the purchase of natural gas by the power plant (which in addition to the taxation at the production source is also taxed on the distribution made by a concessionaire in each state); the acquisition of equipment and services for the construction of the power plant; taxation on the operational and maintenance activities of the plant and taxation on the sale of the generated electric energy. There are three types of taxes: federal, state and municipal (Costa, 1999). A proposal for a wide ranging reform of the Brazilian tax system has been placed this year before the Federal Congress for debate which, if approved, would signify a better distribution of tax collection and improve the competitiveness of Brazilian products and increase the attractiveness for external investments. This is one of the capital points in the strategical plan of the new Government that took office on January 1st.

In view of all these difficulties, as a way of stimulating the increase in electricity generation and to avoid future supply crises, the new government is studying the adoption of measures and the introduction of a new model in the electricity sector. In the view of the authors such measures should consider the following points:

- The creation of a pool to purchase electricity produced in the country. The idea is to establish a mix between "old" energy (produced by power plants already amortized) and "new" energy, with the aim of stopping an eventual price explosion.
- A strong stimulus for the construction of transmission lines in order to minimize bottle-necks in the transfer of energy between the various regions of the country.
- To define the role of alternative/renewable energy in the energy matrix, especially the role to be played by the thermoplants in view of the attractiveness of hydro generated electrical power.
- To renegotiate the price of natural gas imported from Bolivia for thermoelectric generation—especially regarding the updating mechanism related to the exchange rate fluctuations—which should permit the redrafting of bilateral contracts between the power generators and distributors of natural gas.

- To stimulate the state companies to assume a strategic and decisive role in the electrical power generation and transmission capacity (Petrobras, 1999a, b), considering that in Brazil, despite the privatization program carried out in the last 8 years, the investing capacity of those companies is by far superior to the private segment.
- Linked with the previous recommendation, use of the National Social and Economic Development Bank (BNDES—Banco Nacional de Desenvolvimento Econômico e Social) to give incentive to projects in the energy area, including state company projects.
- The definition of a regulatory framework as an incentive for the implementation of distributed generation in Brazil. This would stimulate independent power producers to go into stream, running its own utilities center using natural gas and profiting from several economic advantages of cogeneration systems of low and medium capacities.

5.3. Small and medium enterprises

Industries, regardless of their size, form an excellent opportunity for expanding the internal market for natural gas as an energy source. According to the last revision of Petrobras Strategical Plan issued in June 2003 (Petrobras, 2003) this sector, which includes the demand for natural gas in commercial establishments, is responsible for a forecast consumption of 23.5 million Nm^3/day in 2007 the equivalent of around 48% of the total demand.[8] However, some difficulties need to be overcome in order that companies feel comfortable in making the investments for the conversion of their installations, minimizing the risk of an unsuccessful enterprise. Among these problems we can highlight the following:

- The high costs of converting installations compared to the current values of production plants and other company assets, especially when we consider small industrial plants. The cost of adaptation is often comparable to the costs necessary for duplicating the production capacity. In these cases the businessman always opts for the alternative, to increase the size of the business, preferring to live with the operational difficulties in the use of other fuels such as high-viscosity oils or firewood, for example. This is typically the case in the ceramics industry, a representative market and a traditional consumer of firewood.
- Concerns also exist in relation to the initiatives taken by the distribution companies to construct supply lines to industrial areas. As we already said, the works are of a large scale but easier to be done for supplying industrial consumers rather than residential. This is because industries are generally located in specific areas or non-urban regions.
- Company concerns related to the lack of post sales support for the use of natural gas and about the maximization of the efficiency of energy with its use. These questions are related to the need in the country for technological organizations capable of offering technical and technological support services to industries and guaranteeing that companies that opt for natural gas do not become "orphans" after their decision. The same applies to the equipment and goods industries, which are very new in Brazil, to serve the specific industrial applications of natural gas.
- The clear definition regarding the final price of natural gas as compared to electricity and fuel oil. The problem of taxation and updating of the gas tariff for industrial purposes is similar to those discussed for the case of thermopower plants and is the matter of appreciation from the part of the Regulatory Agency ANP.

The suggested actions to emphasize the consumption of gas in this sector are very comprehensive and also contribute significantly to the development of the market in other sectors studied. For this reason we opt for presenting them under Section 6, Critical analysis.

5.4. Urban piped gas networks

Responsible for a forecast demand in the order of 3% of the consumer market in 2007[9] residential gas is another important topic in the development of the market and which also functions as an anchor for the gas imported from Bolivia. In Brazil, large, developed, urban domestic gas distribution networks only exist in the capitals of Rio de Janeiro and São Paulo. The two local distribution companies (CEG and COMGÀS) have plans for the expansion and modernization of the networks, especially for the substitution of what is called "street gas" (really LPG networks) by natural gas in the two capitals. However, there were delays in the privatization process, particularly in the case of São Paulo, which greatly put back the development of the expansion plans. Although the residential demand for natural gas can be considered very small compared to the industrial demand, we consider that this cannot be disregarded, bearing in mind the potential for the substitution of firewood and LPG by this energy.

Only in the last 3 years there has been an incentive for the expansion of networks in some Brazilian capital

[8] For details about the volume of natural gas Petrobras intends to sell by 2007 see Section 6.1.

[9] Estimated today at 49 million Nm^3/day according to Petrobras (see Section 6.1).

Table 5
Domestic gas distribution networks in some Brazilian states

Distributors	Network (km) in operation	State
ALGÁS	106	Alagoas
BAHIAGÁS	225	Bahia
BR-ES	37	Espírito Santo
CEGÁS	125	Ceará
CEG/CEG-RIO	2246	Rio de Janeiro
COMGAS	3100	São Paulo
COMPAGÁS	250	Paraná
COPERGÁS	195	Pernambuco
EMSERGÁS	53	Sergipe
MSGÁS	58	Mato Grosso do Sul
PBGÁS	66	Paraíba
POTIGÁS	140	Rio Grande do Norte
SCGÁS	319	Santa Catarina
SULGÁS	311	Rio Grande do Sul

Source: Distribution Management, Petrobras.

cities. However, these initiatives are still very cautious due to the difficulties of carrying out the work, which always means disturbance for the population. Table 5 shows the extent of the distribution networks in some Brazilian states at the start of 2003.

We can confirm that the numbers are still very small to make large-scale distribution viable.

Given these considerations about residential gas, we can present the following suggestions for the development of this market:

- To continue the efforts for quantitative mapping of the market by carrying out field surveys to evaluate the potential for connecting new consumers along the routes favorable for the launch of distribution networks; this is also valid for industrial consumers. The big problem now is to make the required works viable and the competitive aspects of natural gas compared to other energy sources such as LPG and particularly firewood in some regions of Brazil.
- The networks should be launched firstly on the outskirts of large capital cities, making up the first distribution rings and avoiding large-scale disturbance caused by the works.
- To emphasize the introduction of engineering support in the distribution companies; many have set up this support over the last 3 years, but some distributors still need to focus on this question.
- To create conditions for new housing areas, shopping centers and other civil construction enterprises to have internal networks for piped gas, adequately adjusted for natural gas; this also requires an effort for standardization within the country which involves the Brazilian Association for Technical Standards[10] (ABNT—Associação Brasileira de Normas Técnicas) and the National Institute of Legal Metrology[11] (INMETRO—Instituto Nacional de Metrologia Legal).

5.5. Vehicle fleet conversion

The consumption of natural gas for vehicles (VNG) has shown a meaningful increase in the country during the past 4 years. Seen as an excellent alternative to substitute the alcohol program[12] and a solution for taxi-drivers in view of the high price of gasoline, the gas appears to be a modern, cheap and ecologically friendly solution for urban transport and is already in use in Italy and Argentina. Fig. 4 shows the evolution of the vehicle natural gas total consumption in Brazil for the period 1999–2002.

The use of natural gas as a vehicle fuel does not involve a sophisticated technology being a widespread practice all over the world. During 2002 Brazil has gone over 300,000 vehicles that use this fuel, putting it among the world's largest markets for VNG reflecting the great impetus for converting vehicles over the past 4 years (Gasparini, 1999b).

Estimates from the Getulio Vargas Foundation (Instituto Brasileiro de Petróleo, ABGNV, 2002), taking into consideration only the substitution of gasoline by VNG, indicate the potential for sales of VNG to grow from 2002 to 2005 at a rate of between 51% and 62% per year, meaning the number of conversions per month will be in the range of 18–25000. The number of gas stations will grow from the current 390 to around 1300 and the number of converted vehicles, currently in the 300,000 range, will pass one million. This will make the country the world's leader in the use of VNG.

Basically the greatest restriction to the increased use of natural gas, as a vehicle fuel, is the logistics of its distribution. The number of gas stations has grown substantially in Brazil over the last few years, particularly in the most populated regions with the largest vehicle fleets.

This is an area that will have to be better explored and which has a growth in demand, today, only limited by the growth of natural gas stations. In our view the most immediate measures to raise the consumption of VNG should be:

- To reduce the cost of the introduction of the necessary infrastructure for adapting gas stations, currently around US$ 300,000 for a gas station with four filling nozzles. The most expensive part of the

[10] Private institution with the support of associated industries for issuing Technical Standards in Brazil.

[11] Official governmental regulatory body for legal metrology.

[12] During the 1980s Brazil issued a well succeeded program to replace gasoline for sugar cane alcohol to run light vehicles. After a great period of success the program vanished due to the price attractiveness of sugar in the international market which directed entrepreneurs efforts to produce sugar instead of alcohol.

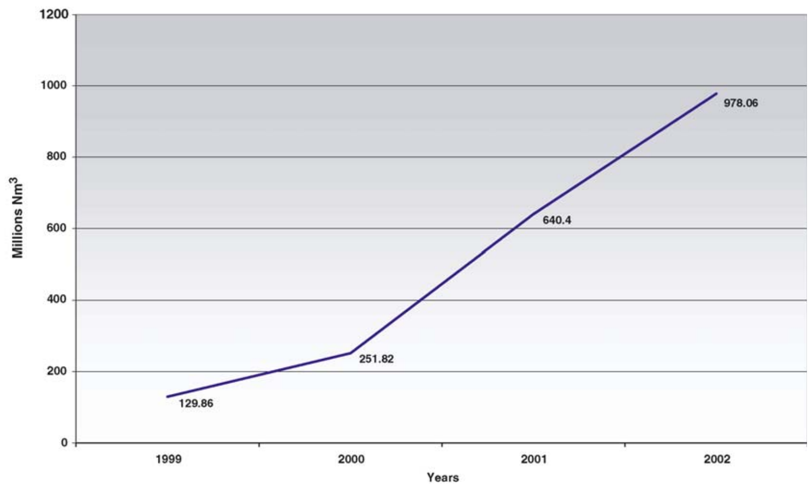


Fig. 4. The evolution of vehicular natural gas consumption in Brazil for the period 1999–2002. *Source*: Petrobras Distribuidora.

equipment is the compression system which costs about US$ 220,000. The cost of the civil construction is approximately US$ 80,000.

- The development of a national system is being considered, which will decrease the cost to around US$ 40,000, eliminating the need of intermediate storage tanks and making this conversion very attractive.
- To develop conversion kits for all national cars, concentrating on cost and reducing the weight of the storage cylinders. These kits are currently imported and only available for some models, costing on average R$ 2500 (around US$ 900), which, in our opinion, is very expensive.
- To develop light and small storage cylinders made of composite material to install in vehicles. Today this is one of the main concerns in the conversion process due to the excessive weight of steel cylinders and due to the space suppressed from the trunk.

6. Critical analysis

We will now analyze the constraints mentioned before for the four economic segments over the framework of their social and economical impacts in Brazil. The capital point of developing a specific goods and services infrastructure in the country as to foster the entrance of natural gas in the energy matrix is also addressed, considering that there is no tradition in the usage of this fuel nor technological skills developed in the country to support the conversion of industrial installations or the development of new applications.

6.1. Scenarios

The first comment in relation to the scenarios is that *none* of the original three scenarios from BNDES or IPEA anticipated problems or radical transformations in the Brazilian economy for the 5 years that followed. Consequently, no great variations were expected in the sector's growth rates or in the composition of exports and imports. The differences expected in the relative performance between the sectors from one scenario to the other were mainly because of the different guidance on the economy relative to the growth of investments (both domestic and foreign) which could affect exports and imports in each sector. But in reality, in 1997, there was the international financial crisis provoked by a crash of the Asian stock markets and at the start of 1999 Brazil experienced a severe foreign exchange crisis.[13]

In Tolmasquim et al. (1998a) work the solution adopted to cope with the Asian crisis was to assume the real economic indicators for the period 1997–1999. All other hypothesis and indicators forecast by BNDES and IPEA for the same period were applied from the year 2000 on, resulting then in a 3-year phase difference in prospects.

In fact, we agree in principal with the proposed postponement, in view of the fact that this international crisis affected one of Brazil's principal long-term strategies: the use of external savings to supplement and finance the low level of domestic savings. In order to avoid the devaluation of the real and with the potential for larger losses of reserves the Government promoted the rise in interest rates and carried out a fiscal adjustment. The impact of the measures were felt as early as November 1997. The year 1998 started with a steep reduction in economic activity, affecting industrial products, agriculture and the service sector, which had

[13] In 1999, the real, the currency introduced in Brazil on July 1, 1994, was still at a parity of 1 to 1 with the dollar. International pressures on the global economy led to this relationship being made flexible, provoking an initial devaluation of 20%. From then there have been frequent fluctuations, which impacted in various ways on the productive sectors in Brazil.

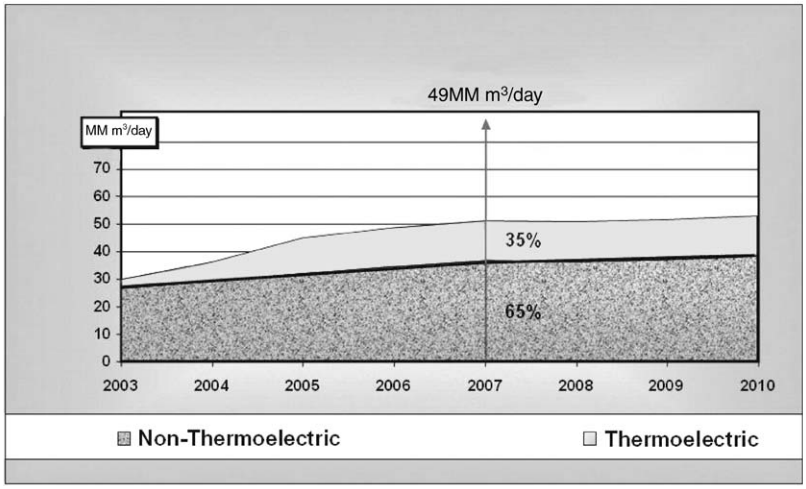


Fig. 5. Natural gas demand curve for the period 2003–2010 in Brazil according to Petrobras forecasts. *Source*: Petrobras Planning Department.

already declined in the final quarter of the previous year. The GDP rate of growth for the first half of 1998 was 0% and 3% in the second half, giving a 1.5% average for the year.

On the other hand, the Brazilian foreign exchange crisis had various effects on the important sectors of the national economy. It forced a continuing policy of high interest rates and affected as well the performance of the commercial balance that was indeed very poor for 1999. By the results obtained from MIPE we can see that the participation of natural gas would reach a maximum of 4.14% in the External Restriction Scenario, 4.82% in the High Growth Scenario and 5.24% in the Sustainable Development Scenario. All of these results, that take into account the effect of the 1997 Asian crisis but do not consider the effects of the 1999 foreign exchange crisis, are *well short of that intended by the Ministry of Mines and Energy and the National Council for Energy Policy*. The target was to be a 12% participation of gas in the energy matrix.

For all those reasons and in order to protect the level of long-term investments and to mitigate the risks of economic waves in global markets Petrobras, being the most important company in Brazil economic scenario and the only natural gas large scale carrier, implements annual revisions of its Strategic Plan. According to the last revision issued in June 2003, the company intends to invest US$34.3 billions in the period 2003–2007 with an annual average of US$6.9 billions (Petrobras, 2003). These figures represent only the company's capital and do not include financial levels that can be raised from foreign investors. Specifically for the natural gas business the amount to be invested is around US$ 1.8 billions or 5% of the total. It is interesting to examine the new revised natural gas demand curve as forecast by the company's Planning Department for the period 2003–2010 (see Fig. 5).

In this curve we can see that taking into account the innumerable problems related to the thermopower plants the emphasis has changed to focus the industrial segment. In non-thermoelectric gas we include industrial applications as a fuel (48%), urban domestic gas (around 3%), VNG (10%), petrochemical applications (3%) and mills reductor (1%). If we project the figures of Table 2 for the Sustainable Development Scenario (the most probable according to the general perception and planning specialists in the company) for the year 2007 we would reach a demand of 37 millions Nm^3/day. Petrobras is optimistic to expect a selling volume of 49 millions Nm^3/day, provided that much effort will be put to develop the distribution logistics and the infrastructure of goods and services to support industrial installations conversions in the years to come (see Section 6.4).

6.2. Problems with thermoelectric power plants

In truth, the introduction of a thermoelectric program was part of a larger plan, the background of which was the restructuring of the Brazilian electricity sector. The basic idea was the introduction of regulatory policies that would produce a competitive environment for the generation and commercialization of energy and the application of new forms of regulation in the sectors that remain as natural monopolies (transmission and distribution). The failure to change the energy model in effect in Brazil was for various political and institutional reasons, highlighting the failures in transition planning from the state management model to the private model. The privatization process of the majority of the generation and distribution companies did not evolve satisfactorily and the delay had serious impact on investments, especially in transmission lines for the large consumption centers. Additionally Brazil was hit by a severe energy supply crisis due to two consecutive years of low rainfall, which led to electricity rationing in all regions except the south between July 2001 and March 2002.

This was really a burden for the economic activity and the population in general halting the growth and stimulating the projects focused on alternative sources of energy. In such a framework there were good prospects for the short-term commercialization of thermoelectric energy. However, the influence of the strong dollar on the cost of construction and generation of thermoelectric power plants, and the price of gas, in addition to the reservoirs recovering their levels since the end of 2001, considerably diminished the attractiveness of these projects to foreign investors. We also saw, at the end of 2002 and the start of 2003, successive and considerable swings in the risk rating for foreign investment in Brazil, because of the uncertainties provoked by the passing of the neo-liberal Government to the new labor party Government.

We believe that large projects for thermoelectric power plants will only be given new impetus by a clear definition from the MME on the role of thermoelectricity in the Brazilian energy matrix. Studies are being developed, to be completed in the last quarter of 2003, for this purpose. If there is no clear policy on prices which favors the use of natural gas in these plants, the energy produced will be expensive, compared to that from the hydroelectric power plants, and the trend will be for the thermoelectric plants to only operate in emergency supply situations and peak operation periods, complementing demand.

6.3. Residential gas and expansion of natural gas for vehicles

The expected consumption in these two sectors is significant, about 13% of the total demand for 2007. The relative percentages are 3% for residential gas and 10% for vehicles.

In the case of residential gas it is clear that the consumption increase will depend on medium and long-term solutions related to the logistics distribution problems. The issue of residential gas is more concerned to social than business reasons. Brazil, as a tropical country, does not need natural gas for heating purposes. Basically it is used for cooking. However, the outlook is interesting for this application as a substitute for firewood in the northern, north-eastern, central-eastern and part of the south-eastern regions, which would be a very positive action in terms of the quality of life of the population and for the preservation of the environment.

Also in large population centers its supply is important from the perspective of the introduction of a domestic alternative to the use of electricity, which for residential purposes in Brazil is very expensive, taking into account the social conditions of a large part of the population.[14]

In commercial applications such as air conditioning in shopping centers, hotels and exhibition halls, we have a totally unexplored area for the application of urban gas, which again has repercussions for the quality of life of the population.

In a similar manner, natural gas for vehicles also has a significant social impact considering cheaper transport costs and the environmental aspects associated to the use of a clean and modern fuel. This sector also offers many opportunities for the development of the goods and services industry, including the conversion of vehicles, adaptation of service stations and even the possibility, in the medium term, of having gas fueled cars coming directly from the manufacturers.

Each vehicle can consume a tank of gasoline or alcohol per day. This is equivalent to $20\,m^3$/day of natural gas. In the cities reached by the Bolivia–Brazil gas pipeline there are around 150,000 taxis and light vehicles belonging to official fleets, 70,000 of them in the cities of Rio de Janeiro and São Paulo. The potential demand for gas for these fleets will be $20 \times 150{,}000 = 3{,}000{,}000\,Nm^3$/day which is equivalent to barely 85% of the consumption of the São Paulo city today.

Reflecting the broad acceptance by the population for the use of gas in light vehicles such as cars, vans and pick-ups, Petrobras launched a pioneering program for the use of gas in urban buses in the state of Rio Grande do Sul. If it is successful, this program will open the way for the large-scale substitution of diesel for buses and trucks, creating an intelligent solution for a country almost without railways, where the transport of cargo is primarily by road. The substitution of diesel for transportation will also lessen the pressure on the national refineries whose process streams are always orientated by the demand for diesel and liquefied petroleum gas.

6.4. Industrial gas—infrastructure of goods and services in Brazil and technological support

Taking into account the innumerable institutional difficulties encountered for the introduction of large thermoelectric power plants in Brazil, priority attention in the sense of incentives for the consumption of natural gas in the country is concentrated in the industrial sector. The most critical aspect of this sector is the lack of an infrastructure of goods and services in the country

[14] Approximately US$100 per MWh.

capable of supporting the post sales activities of natural gas.

In order to stimulate the development of the natural gas market, we consider it vital that suppliers of goods and services are developed in the Brazilian industrial environment. If this is to be an initiative from a company, only Petrobras would have the power to lead such a process, due to its size and its tradition in developing the goods industry sector in Brazil.[15] This action will certainly be adopted by the company if it intends to assume the position of leader in the competitive scenario of the oil and gas industry in the southern cone. There is no way to sell gas if the local goods industry does not respond to the requirements of reliable pieces of equipment at reasonable prices and assured quality. In 1999, a study developed by Alonso (1999)[16] on the natural gas production cycle revealed the essential goods and services that should be provided in Brazil to foster the entrance of natural gas in the energy matrix. From the manufacturing industry stand point these goods are:

- Products and pieces of equipment applicable for the introduction of industrial energy systems which favor natural gas as a fuel. In this segment we include: furnaces, boilers, heat exchangers, high performance burners, small and medium sized electricity generators (up to 30 MW of power), co-generators and drying systems.
- For industrial applications of a general nature, the priority would fall on components for transportation systems and measurement of natural gas, such as special application valves, intelligent gauges, automation centers, flow direction systems, basic measurement components and safety devices.
- For commercial applications it is worth to mention ovens, heaters and boilers for use in industrial kitchens, hospitals, hotels and schools; absorption chillers for use in natural gas commercial refrigeration systems.
- For the distribution of urban natural gas we can point out the production of fittings, connections and equipment/tools for the assembly, in the field, of polystyrene distribution networks.
- As an incentive for the expansion of natural gas for vehicles, efforts should be concentrated on lightweight storage cylinders, conversion kits and compressors for gas stations as mentioned before.

For the supply of services, the best solution for a country of the huge size of Brazil is the introduction of a network of independent establishments or centers specializing in natural gas technology linked to the Federal Technical Schools and the SENAI[17] (Serviço Nacional de Aprendizado Industrial)—National Industry Learning Service, with the support and financial participation of companies. There was a pioneering project carried out in the country by Petrobras and SENAI when the Center for Gas Technology—CTGAS (Centro de Tecnologias do Gás) was set up (Almeida et al., 1997) in the state of Rio Grande do Norte, which is playing large role in the dissemination of industrial projects using natural gas. In the work of Alonso (1999) the services considered essential are the following:

- Education and qualification: Solid education of professionals qualified in the area of natural gas, focusing on the different technologies of use, taking into account the non-existence of qualified institutions with experience and expertise characterized by the availability of the option for multi-specialized education; as a consequence, the understanding of the inter-relationship between information and knowledge must be highlighted as a factor for competitiveness, derived from the technological innovation resulting from the efforts of the professionals in the natural gas area. A recent study carried out by ONIP—National Organization for the Petroleum Industry—a non-governmental institution, showed that there is a prospect of creating 15.600 new employment positions in the oil and gas industry up to 2005. It was shown that 55% of the new places require a BS degree and 45% are for technicians and skilled foremen (Onip, 2002).
- Technical and technological assistance: Careful implementation of a base for the development of services aimed at technological assistance in the area of natural gas, in close cooperation with Research and Development (R&D) groups active in different areas of knowledge with a previously identified interface; bearing in mind that such a need is a result of the immediate demand that is forecast because of the multiple projects under development, the alignment of this service structure should favor the development of a flexible network of service centers, with the capacity to become a technological reference, in niches of the market where there is reduced or non-existent expertise within the country.
- Applied research and technology transfer: Implementation of activities aimed at research and development of new applications for natural gas and continual optimization of production processes that use natural gas as an energy source or raw material. These activities would be classified as Applied

[15] Petrobras has a long tradition in developing suppliers in the local market to support its operations especially concerning innovative pieces of equipment.

[16] This study is being updated for 2003.

[17] Private entity subordinate to the National Confederation of Industry and supported by the Government which is responsible for the education of specialized personnel and for supplying technical and technological assistance to industries.

Research, with the obligation to produce commercial results to deadlines substantially shorter than those of conventional research. To expand on these results we will also have the availability of technology transfer services, spreading the use of gas to very different consumption sectors and stimulating advantageous applications for natural gas in a country such as Brazil with its special characteristics.

- Information: The constitution of a robust database with information on natural gas (new applications, institutional decisions, trends, economic viability of use, information on prices and distribution logistics). This database should be formatted as an information portal, administered by an independent institute with links to various databases of the distribution companies, the Brazilian regulatory body, Petrobras, etc.

We suggest that the project of setting up a Gas Technologies Network be encouraged by the Science and Technology Development Support Agencies, due to its scope and importance in achieving Government targets. Particularly in view of the requirement that some royalties paid on oil and gas exploration activities in Brazil should be assigned to related research and development activities (Presidência da República, Ministério das Minas e Energia, 1997) it is of vital importance that the Brazil's Oil and Gas Regulator—the National Petroleum Agency (ANP—*Agência Nacional do Petróleo*)—should rate support for this network as crucial for building up a strategic technical knowledge database in the energy area.

If the network was implemented along the lines suggested in this work, we would have an Innovation Network of Mobilizing Technology for Natural Gas—RITMO (Rede de Inovação em Tecnologias Mobilizadoras do Gás Natural) (Fonseca et al., 2003).

7. Conclusions

Although the results produced by the Integrated Energy Planning Model (MIPE) indicate that natural gas fails to achieve the share in Brazil's energy matrix targeted by Government entities, it nevertheless varies significantly, reaching over 400% in some cases, with elasticity of over $6.0 \times$ GDP in all scenarios.

It should be stressed that the results for natural gas are somewhat conservative, as they do not include recent efforts to encourage wider use of this new fuel in the energy matrix. With the start-up of commercial operations by the Bolivia–Brazil Gas Pipeline, many projects still on the drawing board should become a reality. These initiatives may trigger a rapid upsurge in the share held by natural gas in this matrix, and this is the very reason why Petrobras figures show a more optimistic prospect. It is important to stress the transition period that will occur in Brazil in the years to come. In January 2003 José Ignácio Lula da Silva, a laborforce man replaced the neo-liberal Fernando Henrique Cardoso as President of Brazil. The new Government established as the main goals the decrease of unemployment, the emphasis in developing the local industry and a huge social program named "Fome Zero" (Zero Hunger Program) aiming to figure out a crucial problem of starving that lay upon more than 45 million Brazilians.[18] In such a framework, taking into account the considerable importance of Petrobras in the development of industry in Brazil as a whole its strength in creating direct and indirect work positions, the company's figures for the Investment Program and demand of natural gas shall be considered reliable. These numbers were released for the public last June (Petrobras, 2003). The growth of natural gas in the energy matrix will slow down after 2007, as all the planned thermopower plants and other important projects should already be concluded by then.

In parallel to technological marketing efforts disseminating the use of natural gas, the activities of a Gas Technologies Network fostering the development of applied research projects designed to discover new uses for gas seem to be of the utmost importance, provided that they are financed by interested enterprises and based on schedules limited to no more than 24 months for patent registration. This should provide leverage for new markets and speed up the maturation rate of the industry, which should peak within no more than 10–15 years. In countries such as Canada, the USA, Italy and the Netherlands—where natural gas holds a large share in the energy matrix and has been a reality for more than 50 years—the steady flow of applied research projects is constantly discovering new uses, enhancing its competitiveness compared to other energy sources.

It is important to recall that the Government target was established in 1993 by what was then the Gas Commission under the MME. In the forecasts drawn up at that time, an economic shock was expected that would curb spiraling inflation, stipulating an acceptable rate for gas with an efficient fiscal and monetary policy, and implementing an effective privatization program. Brazil would return to growth, and an alternative source of energy would be needed to underpin this non-traditional expansion, off the usual route of boosting hydropower supplies or expanding Brazil's oil refining segment.

As several problems have occurred, such as the delay in the preparation and maturation of the Real Economic Stabilization Plan, postponed fiscal adjustments, and the maintenance of the artificial foreign exchange anchor to protect the currency (which has severely hobbled the export capacity of Brazilian industry), in addition to

[18] The whole population is presently 165 millions of inhabitants.

ill-matched privatization processes and the implementation of the Regulator Agencies, it proved necessary to review this target in 2000, based on a fresh list of variables. The target was confirmed mainly due to the success of the Real Economic Stabilization Plan which managed to control inflation below 5% per year. Under the current scenarios, we are of the opinion that the proposed target is still feasible, focusing a new role of gas driven thermoplants and emphasizing the entrance of natural gas in the industrial and vehicular segments.

Anyway, convincing results should be presented through establishing an economic policy that urges tax reform and a keener competitive edge for Brazilian products in order to build up investor confidence and release funds that are already available through international entities for investment in infrastructure projects, such as the thermopower plants. This seems to be in accordance to the directions of the new Government.

The fundamental question of natural gas supply in Brazil is also important in the sense of guaranteeing, in a sustainable manner, the actions required for its insertion in the energy matrix. In principal these actions might be considered a little late if compared to the experiences of other countries, but it must be understood that natural gas will never have the same share in Brazil as it has in other, richer, countries which normally have a demand stimulated by a need for domestic heating.

Currently, Brazil has a well established supply of imported gas, for which the Bolivia–Brazil gas pipeline system was built, linking Bolivia to São Paulo and to Rio Grande do Sul and completing the network up to Belo Horizonte, as Rio de Janeiro was already connected to São Paulo. In the future, the growing demand for natural gas will certainly depend on importing great volumes of gas from Bolivia and Argentina to the South East region and of LNG (Liquefied Natural Gas) to the North East; the North will be supplied by gas from the Urucu Basin (explored by Petrobras) which could reach the North East.

In this way, the Bolivia–Brazil pipeline assumes, as was imagined at the time of its conception, the role of the largest common interest infrastructure project in Latin America. In the matter of the acquisition of new volumes of gas from neighboring countries in the future, Brazil will need to carefully study the position of the United States in the market.

The USA has 3.2% of the world reserves and its consumption is the largest in the world (25.6% of the total). Considering the level of reserves and production the life expectation of the reserves is only 9.2 years which might be increased by new discoveries (Fantine, 2003).

Thus the USA will compete for imports of natural gas with Japan, South Korea and China which could become a large purchaser of this energy source. Europe will also be a competitor, as today it is practically dependant on imports and has a demand (19.5% of the world total) close to that of North America. This means that it will seek to guarantee reserves from Latin America, and become a great competitor with Brazil. In order to have an idea of the scale of the markets, USA consumes 1700 million Nm^3/day of gas per day, that is 616 billion m^3 per year, or to put it another way, the equivalent of the entire reserves of Bolivia or Argentina.[19] Consequently, the agreements that the USA will have to make from now on will practically mean guaranteeing a large part of the world reserves for itself.

It is important to understand that the demand for gas reacts quickly and jointly with the increase in the economic growth indexes, both in the growth of demand for electricity, which favors gas turbine generation and industrial demand.

With the new Government recently installed in the country, the question of thermoelectricity and the investments in hydroelectric power plants will certainly be reviewed, in an attempt to concentrate the use of thermoelectric power plants to supplement the deficits of rainfall and peaks in demand. This will require a complete change in the current model for the electricity sector, which is being thoroughly studied. Emphasis will also be given to distributed generation of electricity and to co-generation, progressively creating a market for natural gas.

Taking into account the high popular approval index of the new Government (more than 53 million people voted for Lula in the last election) today there is a strong expectation throughout the country that there will be economic progress in Brazil far superior to that of last decades. This is the very reason why to Brazilians, natural gas energy means that link to the future, considering the prospects of having a modern, clean and fair-priced energy source to fuel development, create workplaces and help foster the improvement of social welfare.

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[19] The projection is that the maximum consumption in Brazil, 10 years from now will be 100 million m^3/day.

References

Além, A.C.D.de, 1997. Cenários Macroeconômicos 1997–2002. BNDES, Série textos para Discussão, BNDES 56, Rio de Janeiro.

Almeida, E.M.deS., Guerra, M.J.deC., Fonseca, M.deC., Alonso, P.S.R., 1997. Relatório de Missão no Exterior, o Centro de Tecnologias do Gás. SENAI, National Department, Rio de Janeiro.

Alonso, P.S.R., 1999. O Gás Natural na Matriz Energética Brasileira: avaliação global de seus impactos, estratégias para disseminar sua utilização e criação de um suporte de tecnologias para o Brasil. Master's Dissertation, Graduate Engineering Programs Coordination Unit—Rio de Janeiro Federal University Production Engineering Program (PEP-COPPE-UFRJ), Production Engineering Program.

Brealey, I.A.C., Habib, M.A., 1996. Using Project Finance to fund infrastructure investments. Journal of Applied Corporate Finance 9 (4), 25–38.

Costa, P.R., 1999. Perspectivas para a PETROBRAS no mercado de gás. Tendências, Política Tarifária, Distribuição e Implicações Fiscais no Mercado de Gás Natural, São Paulo.

Fantine, J., 1997. Centros de Excelência: uma parceria Governo, Universidades, iniciativa privada. Rio de Janeiro, PETROBRAS Corporate Communications Unit.

Fantine, J., 2003. Setor Petóleo e Gás Brasileiro: um novo momento. Estudo da Coppe-Ufrj entregue ao Grupo de Transição para implantação do novo Governo, Rio de Janeiro.

Fonseca, M.V.deA., Alonso, P.S.R., Fernandes, E., 2003. Ritmo, Rede de Inovação em Tecnologias Mobilizadoras do Gás Natural: uma inovação na gestão do desenvolvimento industrial para o Brasil IV^0 Encontro Brasileiro de Profissionais do Mercado de Gás, São Paulo.

Gasparini, S., 1999a. Empresas têm dificuldade em aprovar Project-Finance, Rio de Janeiro, Gazeta Mercantil, Panorama Setorial, January 12.

Gasparini, S., 1999b. Uso de gás veicular aumenta 72% no RJ e 56% em São Paulo, São Paulo, Gazeta Mercantil, Panorama Setorial, April 7.

Gazeta Mercantil, 2000. Meta de 49 usinas será atingida, diz Governo. São Paulo, 29 de Maio.

Instituto Brasileiro de Petróleo, ABGNV, 2002. GNV—Gás Natural Veicular—Rumo a Liderança Mundial, Rio de Janeiro.

Jabur, M.A., 1999. Novo câmbio paralisa projetos em termelétricas. Gazeta Mercantil, São Paulo, 4 de Março.

Jabur, M.A., Santiago, R., 2000. Risco zero na construção de termelétricas. Gazeta Mercantil, São Paulo, 24 de Fevereiro.

Ministério da Fazenda e Ministério das Minas e Energia, 2000. Dispõe sobre o preço máximo de faturamento do gás natural de produção nacional para as empresas distribuidoras estaduais, Brasília, Portaria Interministerial No. 3, 17 de Fevereiro.

Ministério da Fazenda e Ministério Das Minas e Energia, 2002. Dispõe sobre o preço máximo de faturamento do gás natural importado para as usinas termelétricas inseridas no Programa Prioritário de Termeletricidade. Brasília, Portaria Interministerial No. 234, 22 de Julho.

Ministério Das Minas e Energia, 1998. Balanço Energético Nacional e Balanço de Energia Útil, Brasília.

Ministério Das Minas e Energia, 2000. Institui o Programa Prioritário de Termeletricidade, Brasília, Portaria no 43 de 25 de Fevereiro de 2000.

Ministério Das Minas e Energia, Comissão do Gás Natural, 1992. Relatório da Comissão constituída através do Decreto de 18 de Julho de 1991, para viabilização do aproveitamento do gás natural, Brasília.

O Dia, 2003. Carga Tributária Recorde Economia, Edição de 6 de Junho.

ONIP (Organização Nacional da Indústria do Petróleo), 2002. Demanda de Recursos Humanos para o Setor de Petróleo e Gás para o período 2002–2005. Rev. 2 Fevereiro de 2002. www.onip.org.br.

Passos, M.deF.S.A., 1999. O gasoduto Bolívia—Brasil. http://www.ecen.com/eee10/gasp.htm, 9 de Junho.

Petrobras, 1999a. Documento Interno Petrobras, Anep 020-99, 5 de Maio. Dispõe sobre a contribuição Petrobrás para energia nova em 2001.

Petrobras, 1999b. Geração Termoelétrica. Nova Unidrade de Negócios, PETROBRAS-ANEP, Rio de Janeiro, 28 de Janeiro.

Petrobras, 2003. Plano Estratégico do Sistema Petrobras http://www.petrobras.com.br, June.

Presidência da República, Ministério das Minas e Energia, 1997. Lei 9478, 6 de Agusto 1997 Dispõe sobre política energética nacional, atividades relativas ao monopólio de petróleo e institui o Conselho Nacional de Política Energética—CNPE—e a Agência Nacional do Petróleo—ANP, Brasília.

Rosa, L.P., Tolmasquim, M.T., 1998. A Reforma do Setor Elétrico no Brasil e no Mundo—Uma Visão Crítica, Relume-Dumará, Rio de Janeiro.

Rosa, L.P., Cecchi, J.C., Da Silva, M.O., et al., 1995. O Gás natural na América Latina, no Brasil e no Estado do Rio de Janeiro. Cadernos de Energia no. 8, Centro de Estudos de Energia—ENERGE, Junho.

Santos, E.M.D., et al., 2002. Gás Natural: Estratégias para uma Energia Nova no Brasil AnnaBlume, BR e Fapesp, São Paulo.

Tolmasquim, M.T., Szklo, A., et al., 1998a. A Matriz Energética Brasileira na Virada do Milênio. Centro de Estudos de Energia, PPE/COPPE/UFRJ, Rio de Janeiro, Agusto.

Tolmasquim, M.T., Szklo, A., et al., 1998b. O Modelo Integrado de Planejamento Energético MIPE. Centros de Estudos de Energia—ENERGE—PPE/COPPE/UFRJ, Rio de Janeiro, Agusto.

Veríssimo, R., 2000. Programa de Térmicas exigirá R$12 bilhões. Gazeta Mercantil, Rio de Janeiro, 25 de Fevereiro.

Fernandes E. is an architect with an M.Sc. in Transportation Engineering from Rio de Janeiro Federal University and Ph.D. in Production and Systems Engineering from the Brunel University in London. He is a Professor with the Production Engineering Graduate Program run by COPPE/UFRJ where he lectures on Strategic Planning Oil and Gas Segment Strategy, and Services Sector Strategy. In the past, he has also lectured on Engineering Projects, Statistics and Management Accounting in both undergraduate and graduate courses. He coordinates the Brazilian Chapter of the World Confederation of Productivity Science and is a Fellow Member of the World Academy of Productivity Science. His current field of research is related to Corporate Strategy, Productivity, Competitive Intelligence and Establishing Centers of Excellence. He can be contacted at the following address: Universidade Federal do Rio de Janeiro, Centro de Tecnologia, Bloco F, sala F108. COPPE-UFRJ, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, Brazil, cep 21945-970. Tel. (fax): 55-21-2562-7044. E-mail: elton@pep.ufrj.br

Fonseca M.V.deA. has a Degree in Chemical Engineering from the Rio de Janeiro Federal University (1978); M.Sc. in Hydrometallurgical Chemical Technology from COPPE/UFRJ (1983); D.Eng. from the Polytechnic School, University of Sao Paulo (1990) in the glass and vitro-ceramics area; Assistant Professor at the Chemistry Institute, UFRJ, where he lectures on matters related to the ceramic materials field, and Contributing Professor, Production Engineering Graduate Program, COPPE/UFRJ; he has taken out three patents with over 70 papers published; he is a consultant in the fields of the safe disposal and recycling of industrial solid wastes, steel-based feedstock for continuous casting plants, knowledge management, market creation and innovation. He can be reached at the following address:

Universidade Federal do Rio de Janeiro, Centro de Tecnologia, Bloco A, Instituto de Química 7^0 Andar, Cidade Universitária, Ilha do Fundão, Rio de Janeiro, Brazil cep 21949-900. Tel. (fax): 55-21-2590-0990. E-mail: vfonseca@iq.ufrj.br

Alonso P.S.R. is an Electronic Engineer with a degree from the Rio de Janeiro State University (UERJ) in 1976; M.Sc. in Production Engineering from the Rio de Janeiro Federal University—COPPE-UFRJ (1999). He was the Director of the Petrobras Gas Technologies Center run by Petróleo Brasileiro S.A., a Brazilian enterprise operating in the oil and natural gas segment; and currently heads up the New Products Development Division of the Petrobras Materials Unit. He is also an Assistant Professor at the Engineering Department, Rio de Janeiro State University—UERJ, where he lectures on matters related to Linear Electronics. He is also the Coordinator of Graduate Electronics Projects at UERJ, and a professor for the graduate Mechatronic Engineering Course.