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Natural-gas-powered thermoelectricity as a reliability factor in the Brazilian electric sector

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Abstract

The introduction of natural-gas-powered thermoelectricity into the Brazilian generation sector can be considered as a very complex energy, economic, regulatory and institutional revision. Brazil is a country with very specific characteristics in electricity generation, as approximately 80% of the generating capacity is based on hydroelectricity, showing strong dependency on rain and management of water reservoirs. A low rate of investment in the Brazilian Electricity Industry in the period of 1995–2000, associated with periods of low rainfall, led to a dramatic lowering of the water stocks in the reservoirs. With this scenario and the growing supply of natural gas, both from within Brazil and imported, natural gas thermal electric plants became a good option to diversify the electrical supply system. In spite of the Brazilian Government's efforts to install such plants, the country was faced with severe electricity rationing in 2001. The objective of this work is to show the need to continue with the implementation of natural gas thermal electricity projects, in a manner that allows flexibility and guarantees greater working reliability for the entire Brazilian electricity sector. Taking into account the world trend towards renewable energy, the perspectives of usage of biofuels in the Brazilian Energy Matrix and in electrical energy generation are also analyzed. The very issue of electrical power efficiency in Brazil and its challenges and strategic proposals from the standpoint of Government Programs and results provided so far are presented. The technological constraints in order to put on stream the thermal electric plants are also analyzed. The article concludes with a positive perspective of the usage of natural gas as to be the third pillar in the Brazilian Energy Matrix for the years to come.

Keywords: Natural gas; Thermoelectricity; Biofuels

1. Introduction

During the last 5 years, the large companies in the oil and natural gas industry throughout the world have developed studies of scenarios that point out the important role reserved for other energy sources, as an alternative for the expected exhaustion of oil supplies in the period 2030–2050. In the case of Brazil, studies carried out by the planning bodies of the Ministry of Mines and Energy (MME), in relation to the most probable Brazilian industry growth scenarios for the period 1998–2010 (de Além, 1997), clearly show the important role reserved for natural gas, as a rapid response to the increasing demand for energy, which will be necessary for making sustainable development viable in the country. This subject, of great relevance from the geopolitical and strategical viewpoints, has deservedly been receiving growing attention from successive governments, not only because of the availability of the fuel in our production fields and the initiatives

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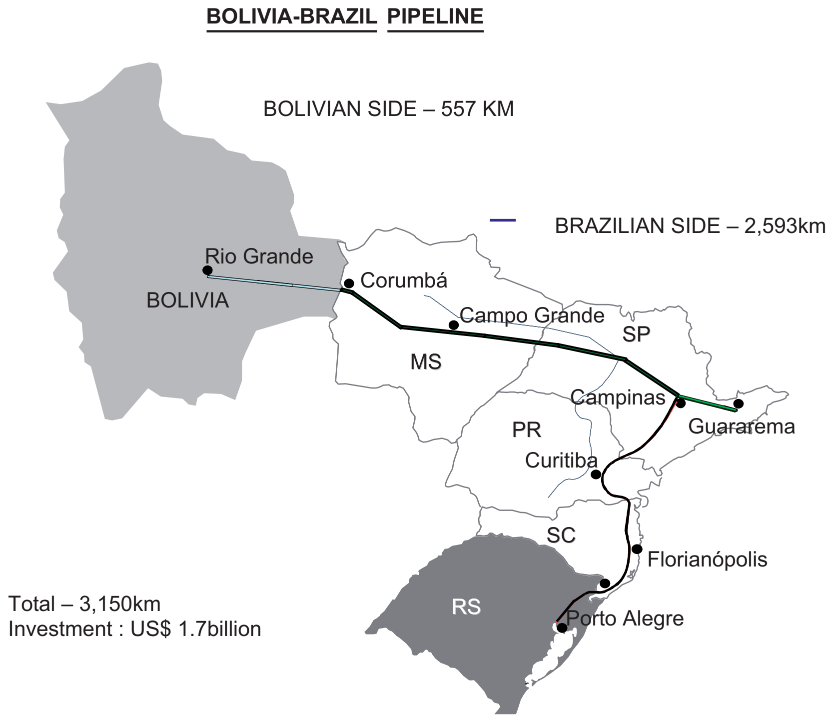


Fig. 1. Overall view of the Bolivia-Brazil gas pipeline. *Source*: TBG—Transportadora Brasileira do Gasoduto Bolívia Brasil.

to increase supply by importing (Fantine, 1995), but also for the appeal of using a superior fuel, which fits in as the best compromise solution between the alternatives of increasing the energy supply and the need to modernize the Brazilian industrial sector (Foss, 2005).

Thus, an important event occurred in the 90s, which continues to have wide repercussions on questions of energy supply for Brazil and, in particular, for the oil and gas industry; this was the decision, taken in 1992, by the Gas and Energy Commission of the MME (Cogas/MME) (Ministério das Minas e Energia (MME), 1992) to increase the participation of natural gas in the Brazilian Energy Matrix, then at 2.5%, to 12% by 2010. This decision became an institutional target of the Ministry, and was later endorsed, in 2000, by the National Energy Policy Council (CNPE), the body responsible for establishing policies and guidelines for subjects related to energy in Brazil.

The government's strategic objective, already accounted for in the tactical planning of Petrobras and Eletrobras,[4] led to important, concrete initiatives in enterprises, of which can be highlighted the 3150 km Bolivia–Brazil gas pipeline, whose commercial operation to São Paulo began in June 1999. At its maximum capacity, the gas pipeline will make 30 million $N\,m^3$/day[5] of gas available, the equivalent of the daily production of all Brazilian wells in operation in 2006. Fig. 1 shows the size of the project.

The investments predicted for the period 2006–2011 in natural gas projects rank to US$22.1 billion, of which 80% will be performed by Petrobras. Of these enterprises, two large gas pipelines being built in the Northeast Region are the highlights: Gasene, an integrating gas pipeline between the country's Southeast and Northeast networks, and Nordestão 2, which will take natural gas to the interior of the country. In the Amazon region there is building work for the Coari-Manaus and Urucu-Porto Velho gas pipelines. These projects will substantially increase the supply of natural gas for the country. Fig. 2 shows the trunk gas pipeline network that exists today in Brazil.

The exploration effort in its turn extended the Brazilian natural gas reserves to the level of 11.2 trillion cubic feet (317 billion $N\,m^3$), with significant discoveries in the Santos and Espírito Santo basins. The evolution of natural gas discoveries in Brazil can be seen in Fig. 3.

Taking into account the 2004 proven reserves in Brazil, Argentina and Bolivia and the current consumption of the principal countries of the region (Brazil, Argentina and Chile), there will be a guaranteed supply of natural gas for a period of 28 years (not accounting for the reserves in Chile and the consumption of Bolivia). Fig. 4 illustrates these data.

In respect to environmental issues, the search for ecologically correct industrial products is more than a worry for the world's large companies; it is a necessity, a commitment to the environment. The improvement of environmental standards is among the main reasons for the

[4]Petrobras is a Brazilian mixed economy company principally working in the oil and natural gas segment. Eletrobras is a state-owned company in the electricity supply segment. It is responsible for coordinating the expansion plans for electricity supply in Brazil.

[5]$N\,m^3$ means a cubic meter of gas under standard measurement conditions, i.e. 1 atm of pressure at a temperature of 60 °F.

Fig. 2. Trunk gas pipelines in Brazil.

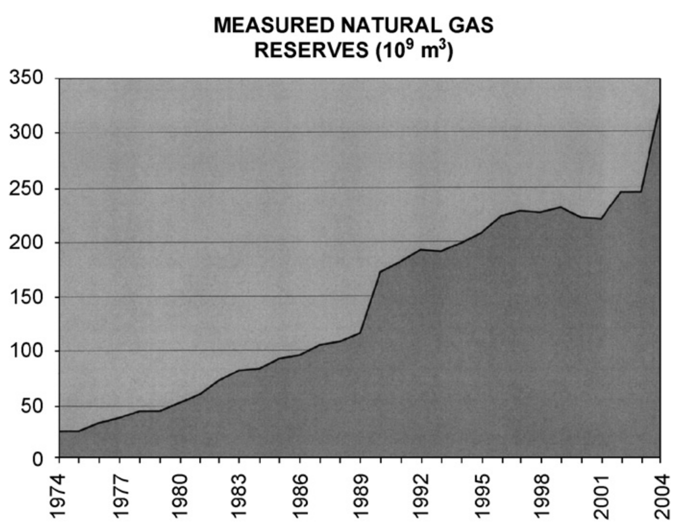


Fig. 3. Evolution of Brazilian natural gas reserves. *Source*: Balanço Energético Nacional 2004—Ministério de Minas e Energia.

expansion of natural gas in Brazil, representing an alternative that is more cost effective and less aggressive to nature.

Within this favorable context, the insertion of natural gas into the Brazilian Energy Matrix made the execution of key projects viable, capable of creating the demand for gas and stimulating the use of the new energy. This created a favorable environment for the introduction of thermal electric plants in the Brazilian generating sector, which, in 2004, had 70% of its energy generated by hydroelectric plants.

The principal reasons supporting the introduction of thermopower plants are related to the great existing interdependence between natural gas and electricity, which favors the characterization of thermal electric plants as key projects, to make the investments in infrastructure for the transport of natural gas viable (Shahidehpour et al., 2005). In addition, the heavy investments needed for constructing hydroelectric plants, associated with the growing international pressure for minimizing environmental aggression, did not favor continuing with hydroelectric projects. Added to these arguments, the fact that the geographic location of these plants is far from large urban centers, implying heavy expenditure on transmission systems, is today the principal limiting factor in the performance of the Brazilian Electrical System.

The objective of this article is to analyze the expected role of natural gas thermopower plants in the stabilization and increase in reliability of the Brazilian Electrical System, discussing its favorable aspects, its restrictions and the important role of thermal electricity as a generation model, offering an energy option for the peculiarities of certain regions of the country and avoiding crises in the electricity supply, such as that which led the country to a regime of rationing in 2001. The perspectives of usage of biofuels in the Brazilian Energy Matrix and in electrical energy generation are also analyzed.

2. Brazilian electricity characteristics

Brazil, a country with 174.6 million inhabitants (2005) and a total area of 8.51 million square kilometers (km^2), has some interesting particular characteristics regarding electric energy generation. Among those we can mention its favorable topographical and rainfall conditions, vast water resources, its continental dimensions favoring the use of renewable energy resources and a generation model based almost entirely on hydroelectricity.

Especially after the second world war, Brazilian electricity policy was aimed at the exploitation of this potential due, firstly, to the proximity of a good part of these water resources to the consumption areas and, secondly, the perception at that time that Brazil was a country relatively poor in fossil fuels, especially hydrocarbons. As a result of

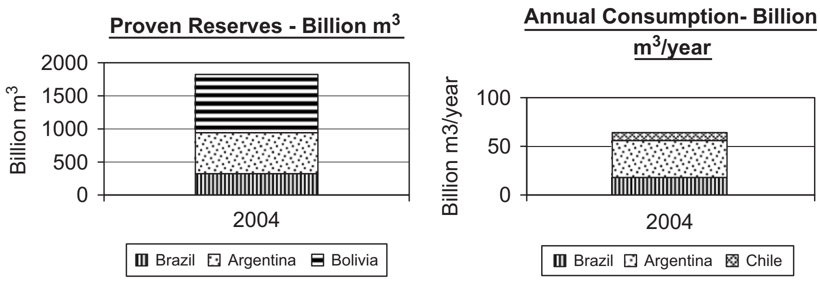


Fig. 4. Natural gas reserves in the Southern cone. *Source*: BP Statistical Review June 2005.

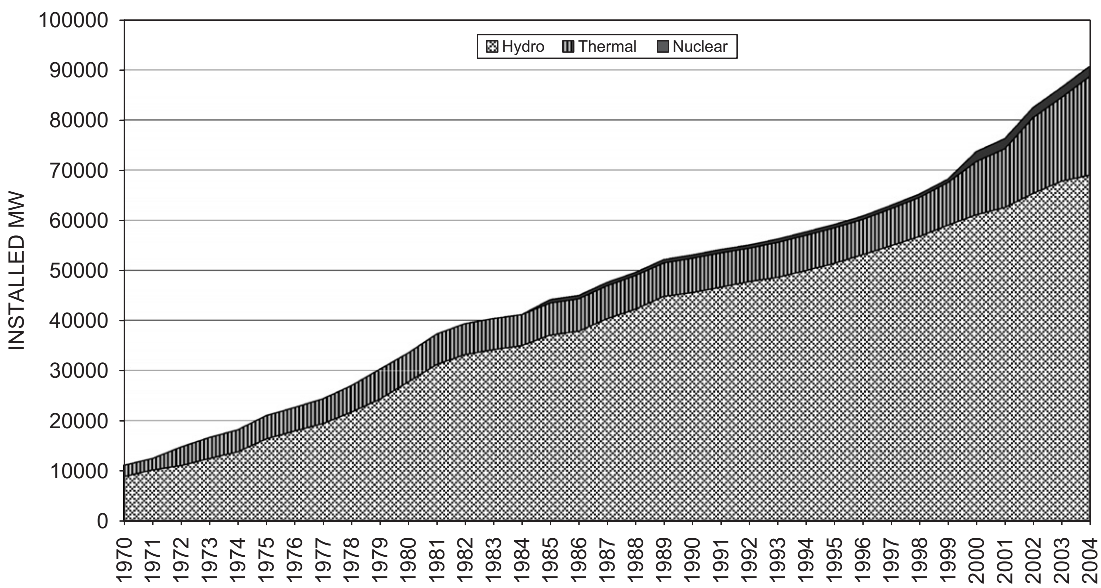


Fig. 5. Evolution of the electricity-generating capacity. *Source*: Balanço Energético Nacional 2004—Ministério de Minas e Energia.

this policy, the Brazilian electricity system became dominated by the presence of hydroelectricity plants in its generation sector. Fig. 5 shows the evolution of the installed capacity of electricity generation in Brazil. As the potential water resources close to consumption centers were exhausted, the limits of the Brazilian electricity network expanded. Therefore the Brazilian generation sector became characterized by large hydroelectric plants, with multi-year water-regulating reservoirs and long transmission lines, interconnecting the large national subsystems, making up a single national electricity generation and transmission system. Brazil has an extensive interconnected network, covering a large part of the country. However, there are large areas where the network is beginning construction or is even non-existent (Fig. 6). As in all electricity systems, this network has great importance in market supply logistics, as it allows the generators to supply their electricity at various load centers on the system. In the case of Brazil, the interconnected network still has a relevant role in optimizing the use of water.

Fig. 6 shows a view of the distribution of the Brazilian electricity transmission network and Table 1 shows a summary of the transmission network by voltage level. Operational planning of the electricity system is conditional on the randomness of hydrological resources, making thermopower plants applicable only when the reservoirs are expected to be exhausted. Therefore, thermal generation has a complementary participation. The hydroelectricity generators, despite being independent companies, share, according to their individual capacity, the electricity deficits and oversupply observed in the interconnected operation. For the isolated systems, especially in the north of the country, served by fuel oil or diesel power plants and to increase the stability of the transmission network, a sharing mechanism was adopted between all the hydroelectric generators to bear the expenses incurred for fuel in those thermal electricity units.

As in all hydroelectricity systems, the use of the water flow arriving at the reservoir is an essential element in the economic management of the Brazilian electricity system, one of the world's ten largest. This issue takes on a particular importance for three basic reasons: (i) the Brazilian plants have large-capacity storage reservoirs; (ii) there are various plants along the same hydrographic flow; and (iii) the basins have substantial hydrological diversity. These three characteristics cause strong complementary actions between the electricity system's hydroelectric plants

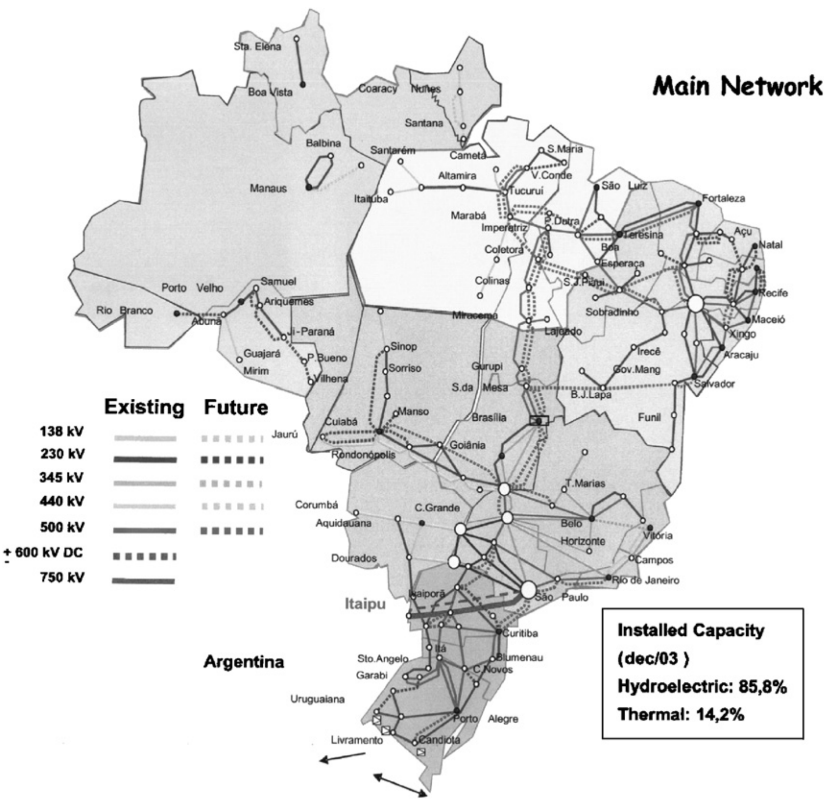


Fig. 6. Brazilian Electricity System. *Source*: Operador Nacional do Sistema Elétrico (ONS).

Table 1
Characteristics and extension of the Brazilian transmission network

Brazilian transmission lines	
Voltage	KM
230	32,998
345	9021
440	6667
500	19,525
600 DC	1612
750	2683
Total	72,506

Source: Operador Nacional do Sistema Elétrico (ONS)—2003.

in the decision as to the use of the water in their reservoirs, and there are significant economic gains arising from the operational coordination of the installed capacity.

It is worth stating that the peculiar characteristics of the Brazilian generating system make it necessary for the operation of the hydroelectric plants to be coordinated, to optimize the productivity of the plants on the same flow. Therefore the operation of the thermopower plants is determined in an overall context, which takes into account the state of the reservoir stocks and the hydrological trend for the next months. When the hydrology is favorable, the hydroelectric sector can produce almost all the electricity required, allowing the entire market to be served even without the thermal power plants, a fact that allows them to remain switched off or with the minimum generation required by contract with the fuel supplier, saving fuel and reducing the overall operational costs of the system.

Considering that the stocks in the reservoirs depend on random climatic conditions and several of the system's reservoirs have the capability for multi-year flow rate regulation, the problem of determining the optimum system operation becomes extremely complex, characterized as a large-scale, non-time-separable stochastic optimization issue. This signifies that the use of a plant in a determined month depends on the analysis of the current conditions in the system and also of its future evolution. Due to its dependence on hydrology, Brazil maintains records of the rainfall in its main hydrographic basins since 1931.

To face the challenge represented by the need to establish the optimum operation of the system, taking into account the mentioned characteristics, simulation models were developed based on stochastic dynamic programming techniques and this control is made by a National Power System Operator (Operador Nacional do Sistema Elétrico-ONS).

The Brazilian Geographic Regions also have different consumption characteristics. Fig. 7 shows the electricity market distribution by region for the first half of 2005.

The South/Southeast/Central West macro-region is characterized by the relatively low consumption growth rate, however with a high consumption density, a situation that substantially reduces the cost of transporting energy to

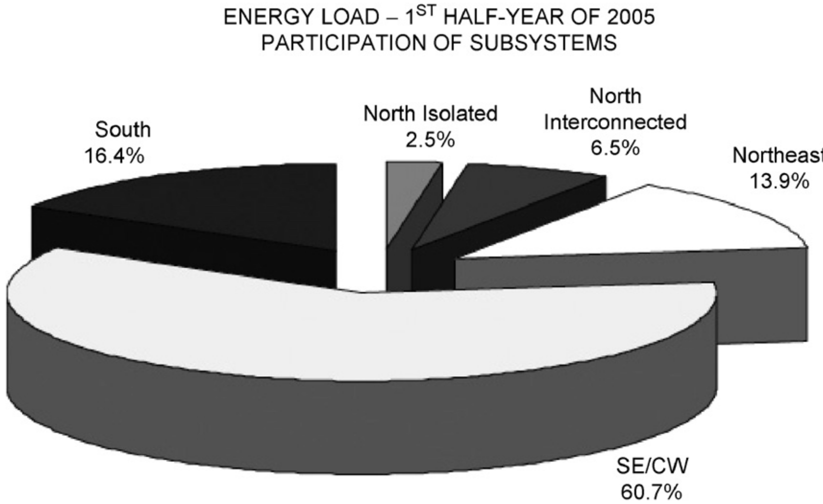


Fig. 7. The Brazilian market by geographic regions. *Source*: EPE—Empresa de Planejamento Energético.

the final consumer. It has a relatively mature transmission network and a reasonable number of generators.

The interconnected system serves the North-Northeast macro-region, with a much lower load than the country's most industrialized region, the Southeast, and with a transmission network that is not very robust. In the North-Northeast Region, there is low population density, consumption is relatively low but growing strongly, and the market is supplied by a small number of plants.

The Amazon region has not yet been reached by the interconnected system and relies on a cluster of isolated systems; it has a relatively low consumption density but a substantial repressed demand. The isolated systems are fundamentally fuel oil thermopower generation. In this region supply costs are very high, and the progressive interconnection of these markets will give rise to opportunities for gains for scale and size, which will allow a significant reduction in these costs. It must be highlighted that only 3.4% of the production capacity is outside of the interconnected electricity system. The consumption production and distribution profile by class, in 2004, can be seen in Fig. 8.

The Brazilian interconnected network was constructed during the last 50 years by various companies, all state owned, which hold the monopoly in their respective concession areas. The transmission lines were designed by the concessionaries with the central objective of taking the electricity from the hydroelectric plants to the centers with the highest population and industrial density in their respective markets. The construction of lines, integrating distinct concessionary areas, was occurring as the concessionaries identified economic benefits in energy cooperation between the regions. As a result of this process, the transmission network is structured to take the majority of the energy generated in the electricity system to the Southeast region, where most of the country's industrial sector is concentrated and which has the largest part of the Brazilian population.

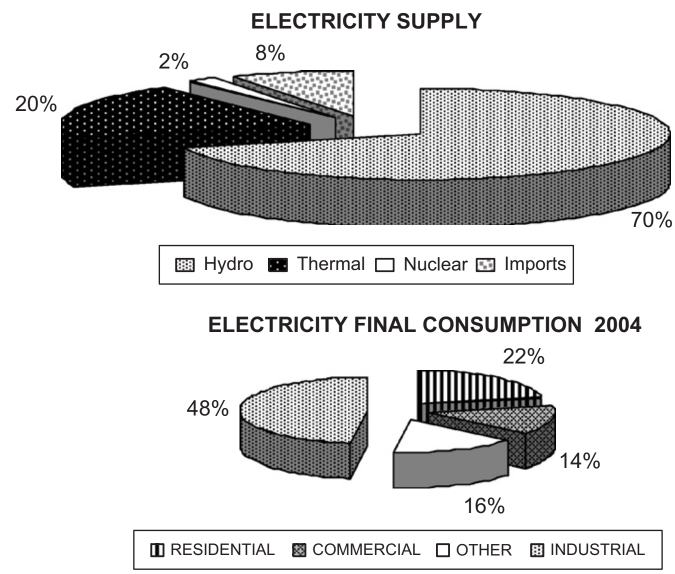


Fig. 8. Electricity production and consumption profile. *Source*: Balanço Energético Nacional 2004—Ministério das Minas e Energia.

Therefore, the Brazilian transmission network is very robust in the Southeast Region; however, the national interconnected system is still fragile at some points. In fact, there are still transmission capacity restrictions that limit the possibility of the flow of electricity between regions.

The Ten Year Transmission Expansion Plan prepared by the MME allows verification of the expected expansion of the transmission network after the 2001 crisis, as shown in Figs. 9 and 10. There is a clear dichotomy between the 2001 plan and those of 2002 and 2003; these last two were very timid compared to the estimated expansion contained in the 2001 plan. However, it is highlighted that the sections put out for tender and those put into service after 2002 represent an effort to recover the time lost on previous expansion plans resulting in numbers that represent the expansion estimate from the 2001–2010 plan. Electricity

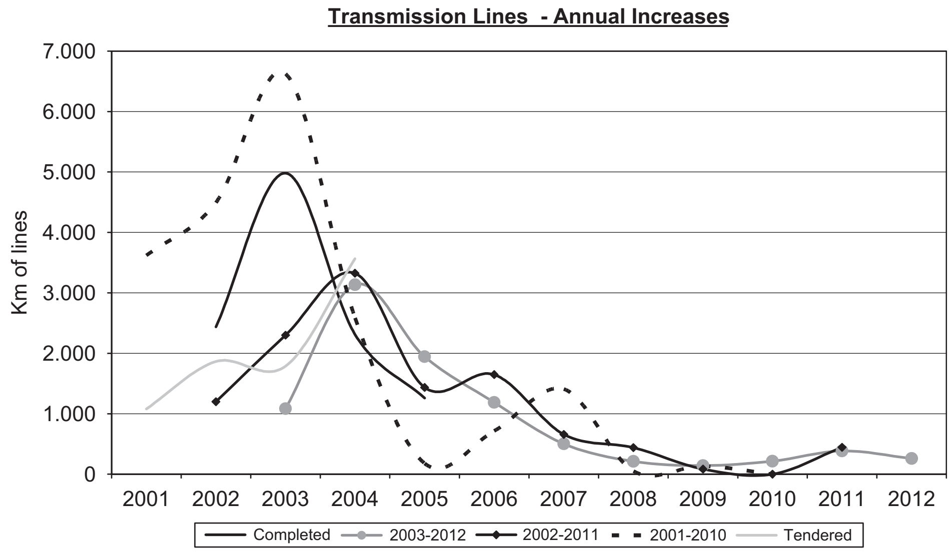


Fig. 9. Transmission network expansion plans. *Source*: ANEEL—Agência Nacional de Energia Elétrica.

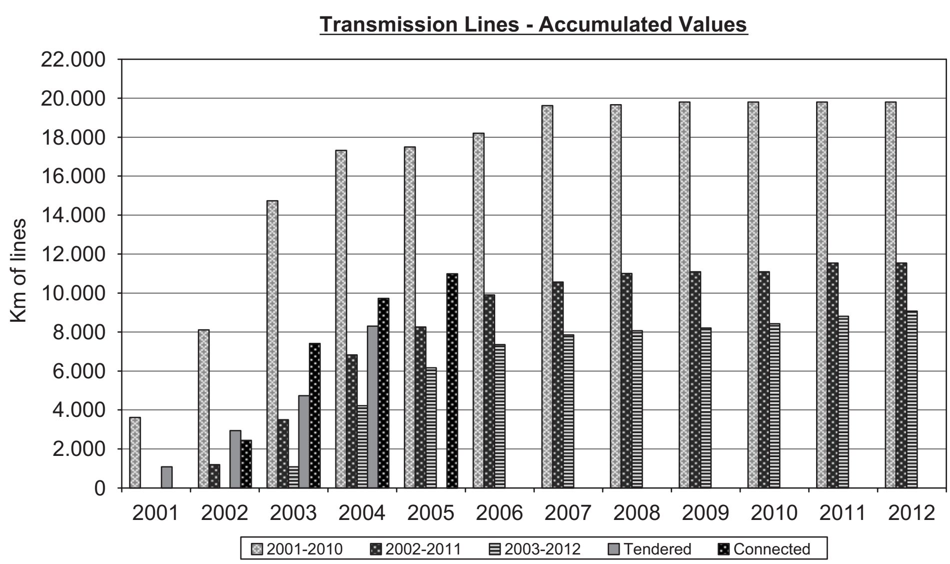


Fig. 10. Transmission network expansion plans. *Source*: ANEEL—Agência Nacional de Energia Elétrica.

sector analysts recognize that this recovery effort constitutes a significant factor in avoiding possible problems in supplying the demand from 2008 on.

3. Brazilian electricity model

In parallel with the technical characteristics, the expansion of the electricity supply in Brazil, during the last decades, came from external financing with strong participation from the Government in strengthening the generation and distribution companies, which are mostly state owned (Andrews, 2005). The vast amount of international financial resources and the high rate of growth in demand allowed for big growth in the Brazilian generation sector, especially in the 70s, made up of a large interconnected system, with big plants, large regulating capacity reservoirs and long-distance transmission lines (de Oliveira, 1998). This situation was reversed in the 80s due to a reduction in the flow of external and Governmental financial resources, which impaired the continuity of the infrastructure work in the electricity sector. The restraint in public utility tariffs, used to reduce inflation, meant that the return on investments made in existing projects was inadequate, compromising still further the economic–financial health of companies in the sector (Szklo and Tolmasquim, 2003).

For many years the Brazilian electricity market was governed by regulated prices, with strong political interference from the Federal Government, establishing unified tariffs for the whole of Brazil. In this context, the companies interacted according to the rules of the cooperative organizations themselves, with the burdens and benefits shared among all agents.

In this model the supply planning and transmission expansion were activities carried out by Eletrobras, the state-owned holding company for the sector, which by its 10-year plans set out the investments for the entire generation and transmission system.

In a general overview, Brazil followed in the 90s the same path as other countries, focusing the privatization of the electricity companies in accordance with the predominant view of the market (Vine et al., 2003) mainly due to the inability of the Government to meet the investment requirements needed to modernize the sector.

The privatization of the electricity companies began in 1995, with the sale of the power distributors and the restructuring of the electricity sector. In this economic model the Government no longer had the role of planning and executing the increase in supply and transmission and would assume the role of regulator and inspector, inducing private investments (Pinto and Almeida, 2003).

The intention of the Brazilian Government was to establish free competition, through a wholesale energy market, in the generation and marketing of electricity, monitored by specific regulations when necessary.

The model proposed the deverticalization of the electricity companies, which meant the separation of the generation, transmission and distribution activities. The sector's current configuration can be seen in Table 2.

The transmission sector continues to be almost entirely state owned. In fact, it sought to establish an institutional, commercial and regulatory model which would allow the possibility of creating solid bases for the future expansion required by the electricity sector (Almeida and de Oliveira, 2000). Therefore, the intention was to reach the following objectives:

- to guarantee a safe and reliable electricity supply for the country and provide electricity for those consumers still not served;
- to create conditions to increase economic efficiency in all segments of the sector,
- to introduce competition where possible, defining the appropriate regulatory scenario;
- to maintain the development of cost-effective hydroelectric plants;
- to create conditions to maintain the privatization program and to make new investments more attractive to the private sector, by adequate allocation of risks; and
- to allow the possibility of a low-risk model with the lowest tariff possible to the final consumer.

Table 2
Private participation in electricity generation and distribution

Segment	Total companies	Private participation (%)
Generation	11	15
Distribution	64	72

Source: ANEEL—Agencia Nacional de Energia Elétrica (2004).

However, important factors restricted compliance with these objectives:

- The need for moderate tariff increases, in order not to prejudice the fight against inflation program, as well as maintaining the consumers' confidence in the sector's reform program.
- An increase in environmental restrictions for electricity generation and transmission projects, principally when they involve flooded areas, relocation of populations and thermal nuclear generation.
- Brazil's previous financial difficulties, which left the banking system reluctant of lending new resources, especially long-term financing.
- The difficulty and slowness in making significant legislative changes.

The tariff adjustment, from 1995, benefited only the privatized distribution sector. The increased distribution prices implied a tariff increase for consumers of more than 100% for the residential sector and around 50% for the industrial sector, without these increases being passed on proportionally to the generation sector. The price readjustment by consumption class for the period 1995–2002 and the evolution of the supply tariffs for the period 1994–2000 can be seen in Figs. 11 and 12, respectively.

Together with the regulatory evolution of the electricity sector underway, the Government changed focus, from the role of a planner and executer to the new role of a regulator and inspector. Serving the market became critical: on the one hand, the demand for energy grew and there was uncertainty and a halt to the construction of new plants to increase supply. On the other hand, the amount of rainfall was not favorable and a change in the form of operating the reservoirs was not considered.

In the period 1991–2000, the demand for energy grew at a rate of 4.1% per annum (average figures) while supply grew only 3.3% p.a., with a small growth in the gross domestic product (GDP) of only 2.8% p.a. (Sauer et al., 2003). This difference had been occurring since the 80s, and even increased from 1995 on as shown in Table 3.

With the operation seeking to guarantee supply, serving the increase in consumption, a sharp drop in the reservoir levels was seen from 1997. This led the country to an electricity rationing situation in 2001 (Fernandes et al., 2005).

It can be seen in Table 3 that if the growth in GDP in the periods 1981–1990 and 1991–2000 had not been so low, the crisis would have occurred before 2001. Figs. 13 and 14 show the situation of the reservoirs in the Southeast/Central West and North/Northeast regions in the period 1997–2001.

4. Thermal electric priority plan

From the entry into operation of the Bolivia–Brazil Gas Pipeline in 1999, as well as for the advantage in

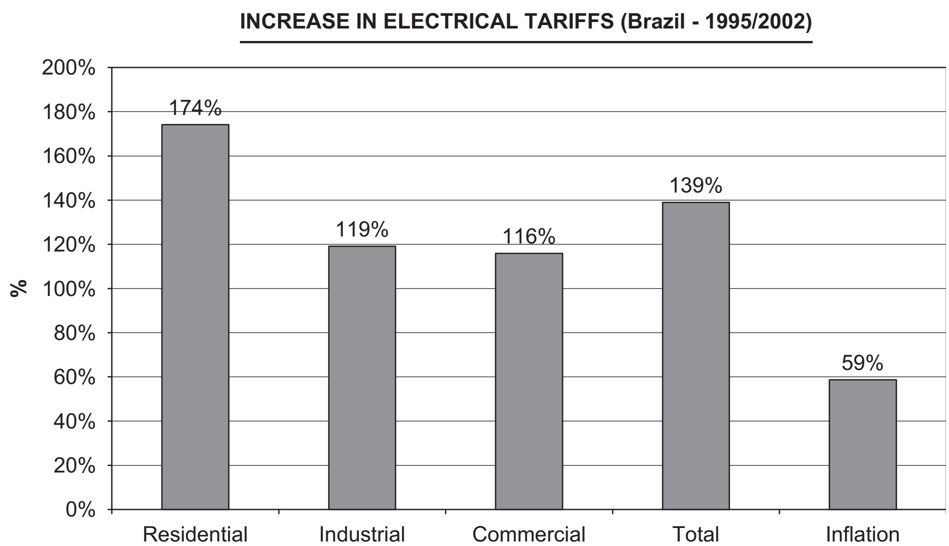


Fig. 11. Supply tariff readjustment by class. *Note*: The total class corresponds to the sum of the other classes in the figure, with the inclusion of other consumptions (public institutions, illumination, irrigation). *Source*: ANEEL—Agencia Nacional de Energia Elétrica.

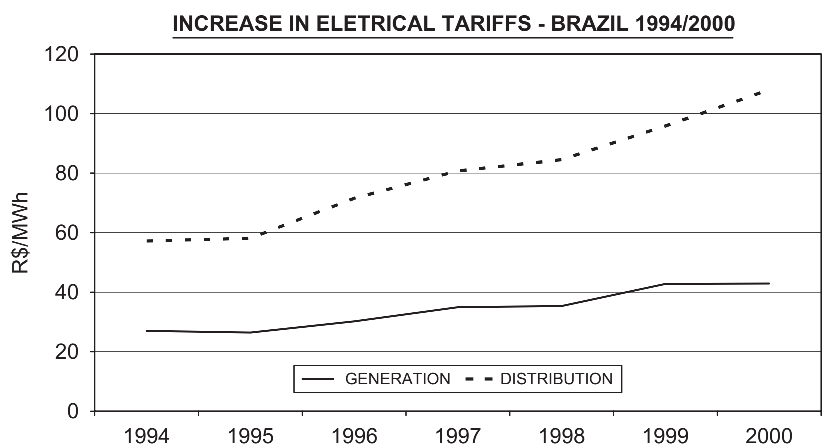


Fig. 12. Evolution of supply tariffs. *Source*: Eletrobras/CCPE/CTEM.

Table 3
Evolution of installed capacity × consumption

Period	Installed capacity growth (%p.a.)	Consumption growth (%p.a.)	GDP (%p.a.)
1981–1990	4.8	5.9	2.2
1991–2000	3.3	4.1	2.8

Source: Eletrobrás, Siese.

construction time of thermopower projects compared to hydroelectric projects, the Government, based on the supply of natural gas, launched in 2000 a program to make viable the use of gas as an alternative energy source for generating electricity (“Convert Gas to Power”: Foss, 2005). This program sought an alternative to reduce the dependency on hydrological conditions and the vulnerability of the transmission system, with the introduction of thermal electric plants along the electricity network (Li, 2005). Brazil, due to the instability of the transmission network, had already experienced a blackout in 1999 that affected most of the country.

The program, called the Thermal Electricity Priority Program (PPT—Programa Prioritário de Termeletricidade), brought a series of benefits for installing thermal electric plants using natural gas, among which was a guarantee of the long-term supply of the fuel.

The natural gas purchase regime has the same conditions as the purchase of the Bolivian gas, which is take-or-pay for 70% of the contracted volume. This could become complicated if the plants are not operating for most of the time, i.e. in a base regime. Another delicate point was the comparison of generating costs to be declared to the National System Operator (ONS), which does not take into account the transmission costs of the hydroelectric power plants. Therefore, the costs of the hydroelectric plants, without the cost of fuel, are always lower than the cost of thermal generation.

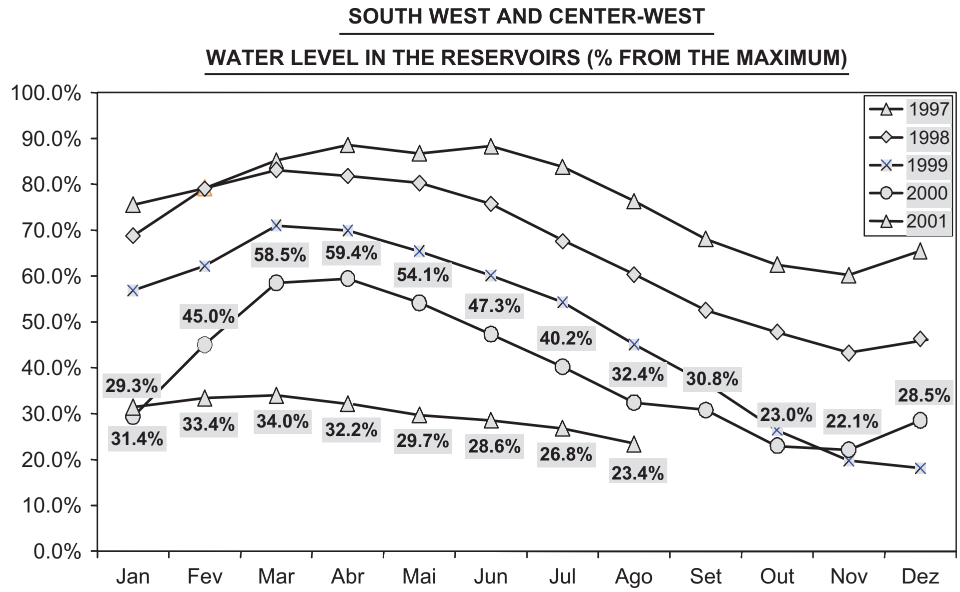


Fig. 13. Reservoir levels in the Southeast/Central-West regions. *Source*: Operador Nacional do Sistema Elétrico (ONS).

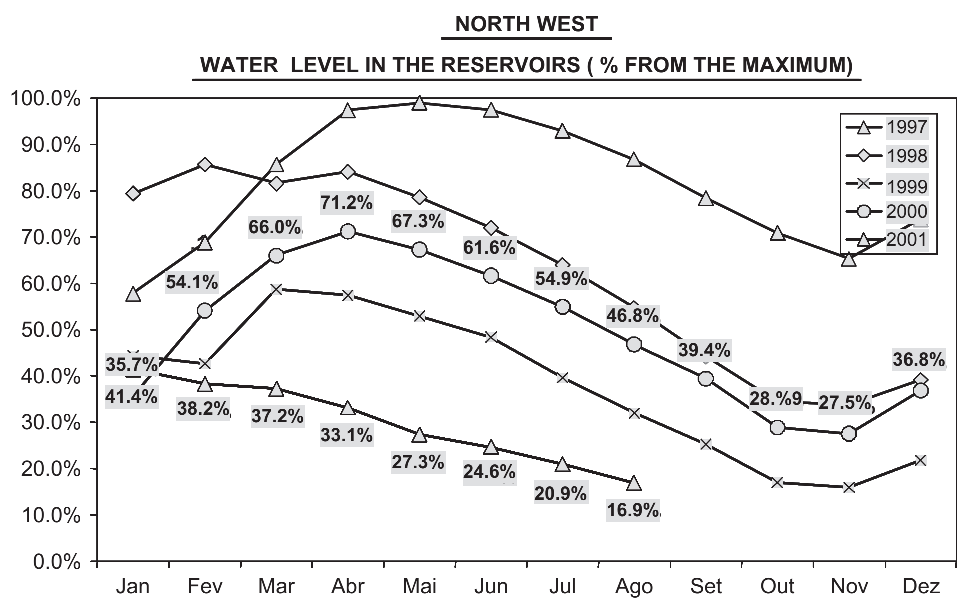


Fig. 14. Reservoir levels in the North/Northeast region. *Source*: Operador Nacional do Sistema Elétrico (ONS).

At first 49 plants were selected, spread throughout Brazil. The additional generation capacity reached 19,363 MW, 91% generated with natural gas. However, few of the projects were implemented, and the majority of those that went ahead had the participation of Petrobras, the state-controlled company. By 2003, only a gas thermal power capacity of 5217 MW had been installed in the country.

Therefore, with the growth in demand, the worsening condition of the reservoirs and the non-entry on time of the new projects, the country passed through a severe supply crisis. Electricity rationing of around 20% of total consumption was imposed on the country, with very damaging consequences for the Brazilian economy. A special body created by the Government administered the rationing, with the application of penalties for those consumers who did not comply with the energy-saving targets.

The 2001 rationing brought, in addition to the damage to the Brazilian economy, a situation worth of mention in terms of available energy. A change of habit of the domestic consumer was observed, which included reducing energy in their day-to-day lives. Also, industry consumers implemented aggressive energy efficiency programs,

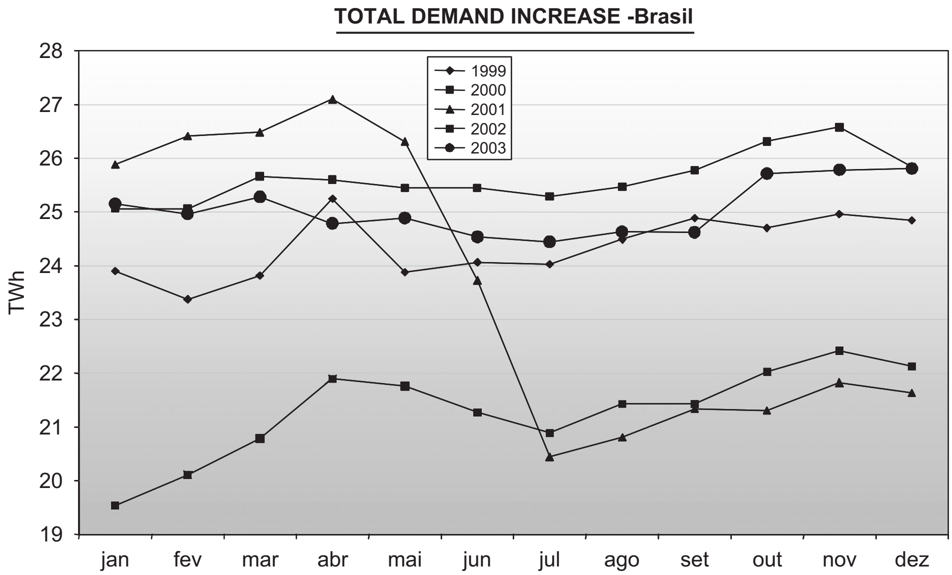


Fig. 15. Evolution of electricity consumption—1999/2003. *Source*: Operador Nacional do Sistema Elétrico (ONS).

leading to a permanent reduction in their electricity demand. On the other hand, a change of habit associated to the recovery of the reservoirs created conditions for a new reality: an excess of energy supply of around 8000 MW. Fig. 15 shows the evolution of energy consumption in the period 1999–2003, where the effect of the July 2001 rationing can be seen.

The reduction in demand took the 2002 consumption curve to levels lower than 1999, and the 2003 curve to levels equivalent to the 2000 curve. With the energy supply excess, the wholesale energy market prices came to a halt. There were no conditions for introducing new thermal power plants, considered more expensive than the hydroelectric energy from the amortized plants, nor incentive for constructing new units.

Currently there are still problems in resolving this impasse. To solve the problem of the stranded costs of investors who constructed thermal electric units, mechanisms must be created to redistribute the risks and losses and a review of the understanding of the real costs and benefits of thermal generation must be undertaken. The current average generation costs are around US$42/MWh for natural gas thermal electricity and US$30/MWh for hydroelectricity, not taking into account the transmission cost (Brunekreef and Mc Daniel, 2005).[6]

5. New Brazilian electricity model—2003

With the change of Government in January 2003, a new energy model was prepared, seeking to offer greater security for investments in energy generation and transmission.

This new model advocated that the energy-planning system should be improved in order to guarantee the expansion of electricity generation, transmission and distribution. An energy-purchasing pool is also being introduced.

After the planning phase there is a bidding for new enterprises, with a guarantee of recovering the costs during the useful life of each project, setting out the transfer criteria and the sharing of generation and transmission costs between the various distribution concessionaires. This system seeks to reduce uncertainties and risks for the producers and consumers.

In this new model, approved in March 2004 (Law 10.848/2004), there will be a tender system for all energy contracting, with the splitting of the so-called ‘‘new energy’’, to serve the expansion of the system, from the ‘‘existing energy’’, for serving the current market. This seeks to guarantee the entry of new generating capacity.

In this new environment it is expected that the main role of natural gas power plants will be to guarantee the electricity supply, minimizing the hydrological risks and conferring greater operational flexibility and reliability to the entire electrical system (Alonso, 2004). A simplified comparison between the new model and the regulatory apparatus in force at that time is shown in Chart 1.

As predicted in the new model, auctions were carried out regarding existent and new energy packages in order to fulfill the demand expansion. The first auction regarding the ‘‘new’’ energy took place in December 2005 and traded a total amount of 3.286 MW featuring dispatch dates for the period 2008–2009. From this total, 2278 MW correspond to thermal generation, 61% being provided by natural-gas-fired thermopower plants.

[6]The relationship between the policy for the return on investments in energy and an adequate energy supply are detailed in Brunekreef and Mc Daniel (2005).

OLD MODEL	NEW MODEL	OBSERVATIONS
Market competition (tender for public assets and gradual freeing of the market)	Competition for the market (competition for generation by tender for new enterprises and consumption blocks)	- Generation competition does not unlink the business from the public service concept - Generation investor risk is assumed by the integrated system
Tender by highest return for use of a public asset	Tender by the lowest price for the energy offered	- Each enterprise receives a permitted income based on the price of the tender - Under these conditions the generation area will became a type of joint ownership, similar to that of transmission
Indicative planning	Structured determinative planning and with indication of priorities for the tenders	- Activity under the responsibility of the Energy Planning Company EPE -Empresa de (Planejamento Energético)
System operated by ONS (National System Operator) a private limited company	System operated by ONS at first, preserving its current legal structure)	- Changes may occur in its governing structure
MAE (Wholesale Electricity Market) Accounting and settling contract deviations and short term transactions	The institution of a body to administer energy contracts (electricity supplied by the generators with various prices and composition of a supply tariff to the distributors)	- Responsible body: CCEE – Electricity Trading Chamber - MAE extinct, its remaining functions incorporated into the CCEE
Consumers freely served by Distributors / Generators/ Independent Producers (PIE) / Traders	Consumers freely served by Independent Producers / Traders	- The free market tends to be lower than the regulated market

Chart 1. Old model × new model comparison.

6. Biofuels in Brazil distribution, current situation and potentialities

The option to implement a natural gas thermal complex, supported by Brazilian reservoirs and by a long-term contract of gas supply agreed with Bolivia, represents a secure and reliable option to meet environmental requirements, which are getting stricter, mainly referring to the environmental impact caused by flooded large areas resulting from the creation of dams. If problems arise from natural gas supply, there is always the possibility of transforming thermal power plants into bio-fuel (dual fuel), using diesel, alcohol, or fuel oil, but it does not mean that the consumption of other alternative products, other than natural gas, has to be separated from the concern of environmental sustainability.

Brazil, according to its own characteristics and continental dimensions with large areas available to plant sugar cane and vegetables, stands out in the international scenario as a nation that has great expectations to explore economically power supply options derived from biofuel use. The global power scenario, which is suffering with the increasing demand of power supply, high costs of power, refine capacity reaching its limit, geopolitical instability, conflicts in countries that supply oil and the large dependence of non-replaceable power sources, also favors the implementation of biofuels as a secure alternative to the country in many segments of economic activities. Fig. 16 presents the profile of the Brazilian Energy Matrix at the end of 2005 (Ministério das Minas e Energia (MME), 2002, 2003, 2004). We can observe the significant participation of sugar cane, intended for obtaining alcohol, sugar cane bagasse and biomass (comprehending firewood, rice peel and other fuel), which is more used as industrial fuel. Fig. 17 shows that alcohol has the most meaningful participation as fuel in the national fleet of light vehicles. Andre alcohol is mixed with gasoline in a proportion of 25% in volume, and hydrated alcohol is directly used as

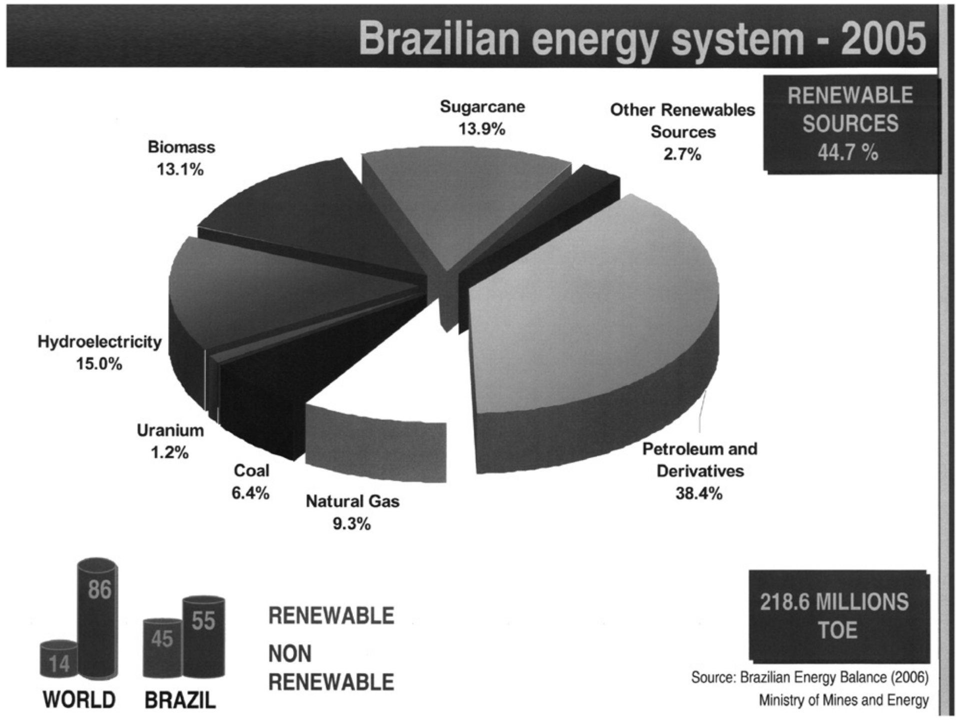


Fig. 16. Brazilian Energy Matrix in 2005. *Source*: Balanço Energético Nacional—Ministério das Minas e Energia.

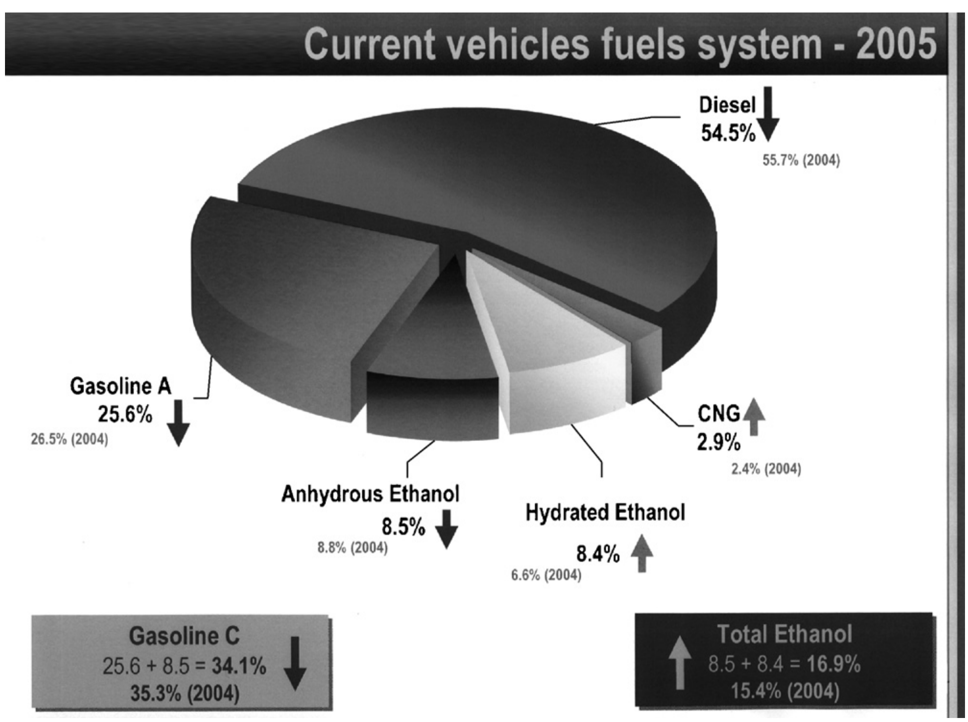


Fig. 17. Consumption matrix of Brazilian Vehicle Fleet. *Source*: Balanço Energético Nacional—Ministério das Minas e Energia.

an automotive fuel in vehicles known as flex-fuel vehicles (bi-fuel using gasoline and hydrated alcohol).

Following the development of governmental programs that focus on the implementation of biofuels in Brazil, particularly biodiesel, a meaningful change in the Brazilian Energy Matrix is expected by 2023 as Fig. 18 shows. It is possible to verify that alcohol, biodiesel, and biomass participation will achieve 29.4% of the Matrix, with a meaningful increase in biodiesel that will reach 10% of all diesel produced in Brazil, resulting in a participation of

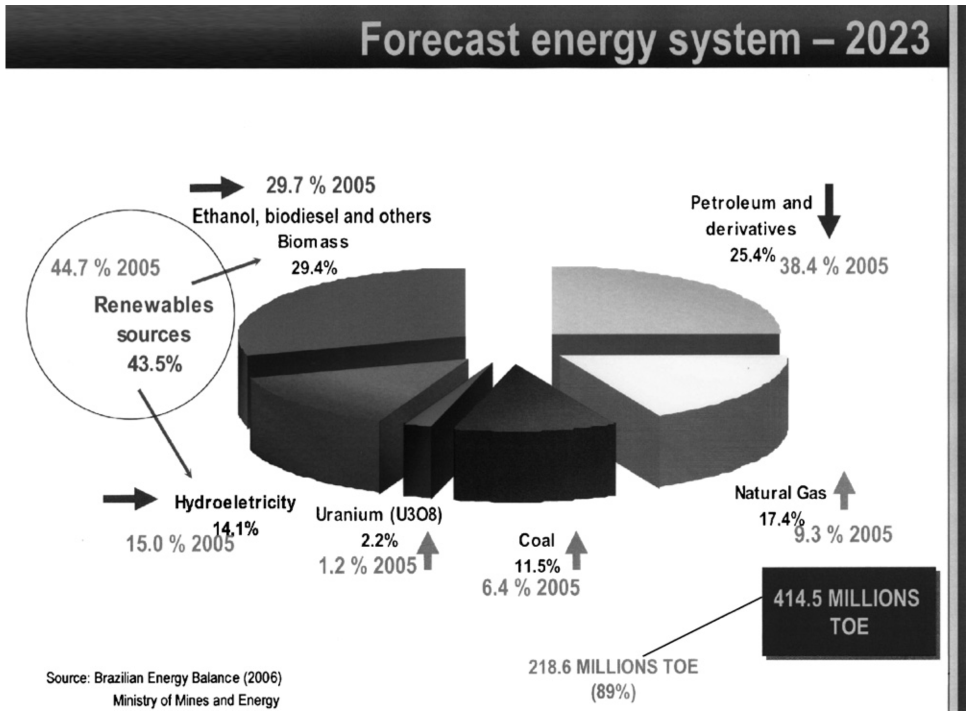


Fig. 18. Brazilian Energy Matrix in 2023. *Source*: Balanço Energético Nacional—Ministério das Minas e Energia.

5.5% in the profile of national vehicle fleet demand (Martins, 2006), including heavy and light vehicles.[7]

Next, we will present a brief analysis of the most important expectations of biofuels, alcohol and biodiesel produced in Brazil, alcohol, and biodiesel.

6.1. Alcohol

The first experiences with ethanol as a vehicle fuel in Brazil started in 1925, when the first tests with alcohol and gasoline mixture were carried out. Brazil developed its first design of an entirely alcohol-powered car in 1979, and during the 1980s a significant increase in the fleet of alcohol-powered vehicles was witnessed. During the 1990s, before the increase in sugar price in the international market, Brazilian sugar cane producers had as their priority the production of sugar, resulting in the rise in alcohol price in the domestic market, which caused a shortage of automotive fuel. In 2000, successive increases in gasoline price in the domestic market tied up with successive price rises in crude oil in international market favored once again the use of alcohol as automotive fuel. Therefore, the program re-appeared with a new automobile concept: vehicles that use flex-fuel or bi-fuel technologies, which are able to work with any mixture of alcohol or gasoline.

In July 2006, the participation of flex-fuel vehicles in the national fleet of passenger cars represented a total of 76% (Martins, 2006). Flex-fuel vehicles' current production in Brazil is divided among 7 multinational car industries that produce around 89 different models of flex-fuel vehicles. For over 25 years, the domestic market made full use of alcohol, a reasonable amount of knowledge of the type of technology has been amassed, as can be seen in Fig. 19. Four large research centers concentrate their knowledge of the subject to transform alcohol into a product with high aggregated technological value in Brazilian exports.

6.1.1. Perspectives for alcohol and main challenges

The perspectives for the national alcohol production from 2005 to 2015 can be analyzed in Fig. 20. It can be noted that an enhancement of 200% in alcohol domestic demand is expected, corresponding to the increasing number of vehicle fleet and other industrial applications. It can also be seen that the possibility of launching alcohol in the international market is increasing, which would consume 12 million cubic meters of alcohol in 2005. The perspectives for alcohol use in thermoelectric plants involve technological and economical considerations, which will be discussed in Section 6.3.

The following items represent the main challenges to consolidate alcohol industry in Brazil and in the world:

- Technological
  - pulp hydrolysis;
  - biorefining (alcohol + chemical products);
  - biotechnology: increase in pulp level;
  - farming technologies that allow pulp recovery, whose loss during process use nowadays is about 30%; and
  - bioelectricity: possibility of generating up to 3000 MW by 2011.

[7]As observed in Fig. 17, diesel represents near 55% of power consumption by vehicle fleet in Brazil. If biodiesel enhances its participation to 10% of the total diesel produced in volume, we will have a final participation of this fuel in vehicle fleet demand of 5% in volume.

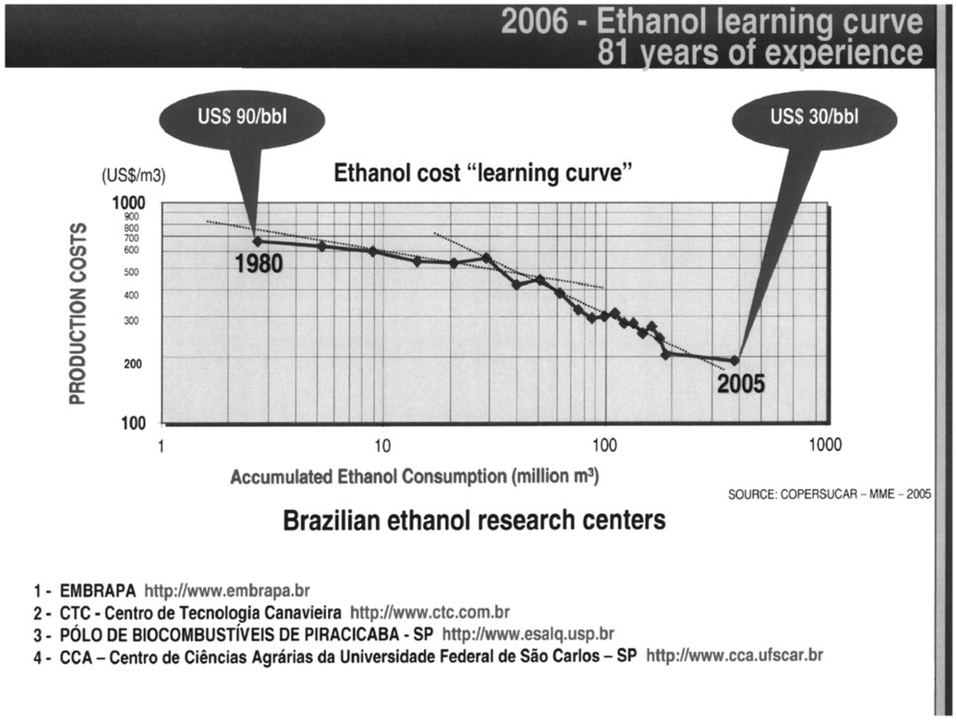
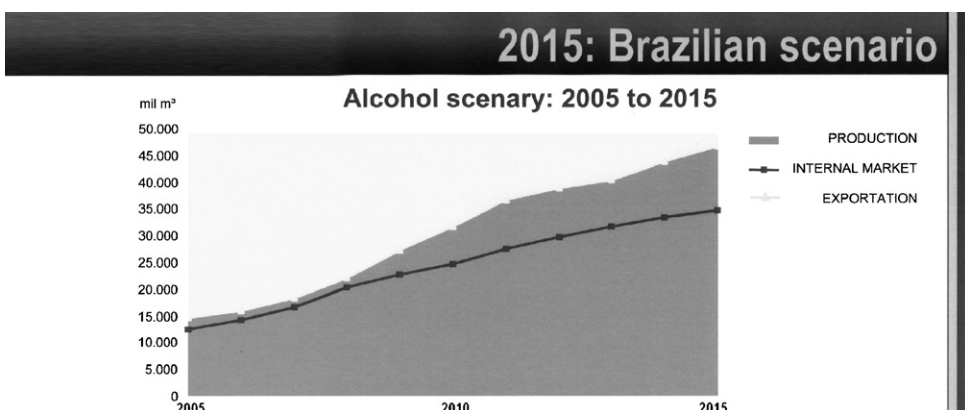


Fig. 19. Brazilian learning curve regarding the domain of alcohol technology. *Source*: Petrobras Distribuidora BR.



	MARKET (m^3)		
	INTERNAL	EXTERNAL	TOTAL
2005	12.468.270	2.173.017	14.641.288
2006	14.254.079	1.675.800	15.929.879
2007	16.626.158	1.862.000	18.488.158
2008	20.323.967	1.862.000	22.185.967
2009	22.854.369	4.561.900	27.416.268
2010	24.882.777	6.889.400	31.772.177
2011	27.577.474	9.216.899	36.794.374
2012	29.792.846	9.310.000	39.102.846
2013	31.833.209	8.658.300	40.491.509
2014	33.463.118	10.706.500	44.169.619
2015	34.911.597	12.103.000	47.014.597

Source: IDEA

Fig. 20. Alcohol market in Brazil and in the world for 2005–2015. *Source:* Petrobras Distribuidora S.A.

- Social
  - Social inclusion as alcohol is a cheap fuel and is available to the low-income population.
- Economic
  - turn alcohol into an international commodity; and
  - encourage new alcohol producers.

6.2. Biodiesel

The main reasons to implement biodiesel in the Brazilian Energy Matrix are related to economic, social and environmental aspects. Regarding the economic aspect, the main force is related to high prices of crude oil in the international market, even when considering that Brazilian dependence on imported crude products is low. In the social aspect, the necessity of creating new jobs and establishment of rural population in their original regions are the main concerns. The environmental aspect is justified by the implementation of a new renewable fuel. The main challenge of the biodiesel implementation project in Brazil is to implement a self-sustained power project, considering power supply price, quality and warranty, which may promote other social inclusion projects for future generations. In Brazil, there is a regulatory framework to determine minimal percentages of biodiesel mixture with produced diesel, besides regular monitoring of governmental bodies to implement this new power supply in the market. Currently, the mixture percentage is of 2% in volume, and as of 2013 this number will increase to 5% in volume.

Fig. 21 presents the main producer sources of biodiesel in Brazil, highlighting soy production that corresponds to around 95% of the total produced amount. Biodiesel market in Brazil is still in the beginning, and has its basic focus on the addition of soy biodiesel to the traditional diesel. There are around 3400 gas stations in the country that sell nearly 650,000 m^3 of biodiesel B2 (a mixture of diesel that has an application of 2% in biodiesel volume.) Another expressive volume, of around 537,000 m^3 (Martins, 2006), is directly sold to large clients. Even considering that this fuel is new, there are 41 bases and terminals in Brazil involved with the distribution logistic of biodiesel B2.

6.2.1. Biodiesel trends in Brazil

During 2006–2007, the main tendencies related to biodiesel use in Brazil are

- relevant increase in production capacity;
- new projects in large-scale and continuous production;
- enhancing quantities of biodiesel acquired in public auctions conducted by the regulatory body—National Petroleum Agency (ANP)—with the participation of producers and importers.

From 2008 to 2013 the mixture of 2% in volume will be mandatory, and as of 2013 the mandatory mixture will be 5% in volume. This opens new perspectives regarding the increase in biodiesel mixtures in volume, depending on the power supply production curve.

6.3. Perspectives of bio-fuels in thermoelectric plants

The planning of power offer expansion in Brazil, under the responsibility of the Power Planning Company (EPE) in connection with the MME, considers the power generation from renewable and non-renewable sources, which complement the production of hydroelectric plants, which are the base of the Brazilian interconnected system. Cost analysis of power generation originated from renewable sources such as wind, sun and biomass power supplies demonstrates that these sources are not very competitive in the market compared to power generation from conventional sources. Just to give an idea, using the same basis

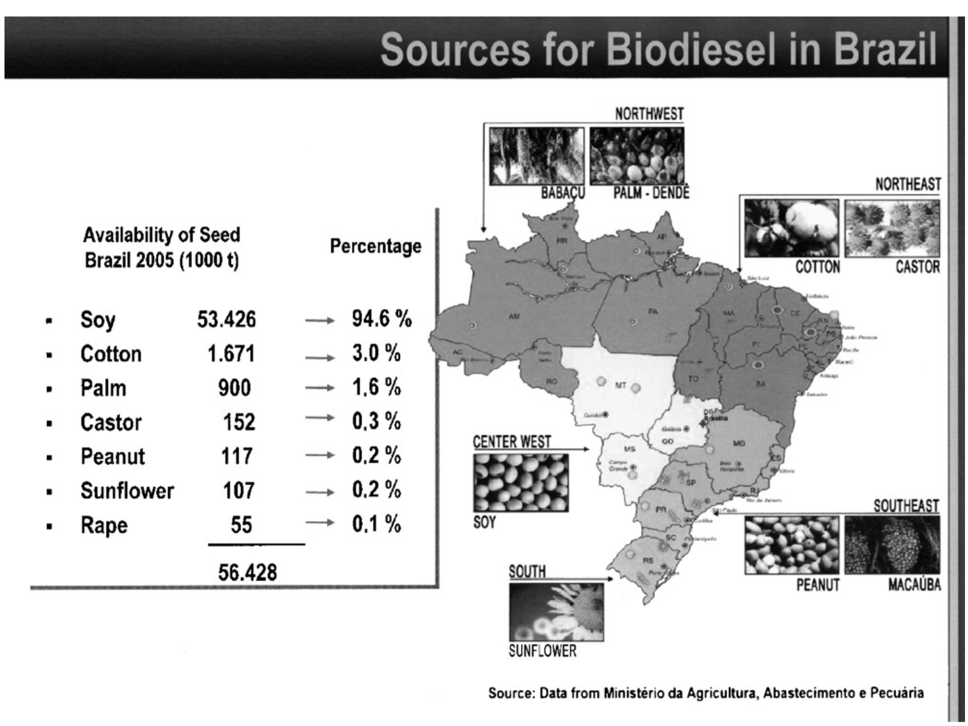


Fig. 21. Biodiesel production sources in Brazil.

presented in item 4 for the costs of thermoelectricity (US$ 42.00/MWh) and hydroelectricity (US$ 30.00/Mwh) in Brazil, the cost of power generation using biofuels (alcohol in a first approach in Brazil) would be US$ 70.00/MWh. Thus, natural gas remains the best alternative to hydroelectricity generation in Brazil, provided that the competitiveness of biofuel sources is still disadvantaging. The Brazilian power model is based on low rates, always prioritizing power generation with low operational costs to complement the power generation of hydroelectric plants. Taking into account future technological developments and the lowering of costs related to producing the biofuels, these may be considered an alternative in the long term for power generation.

7. Power efficiency in Brazil challenges and strategic proposals

Power efficiency must be seen in its economic context at short and long term. At short term, the best strategy is the optimization of resources available and there is no room for final formulations. At long term, with integral planning and effective management of the resources allocated, the technological innovations are vital factors for diversification, on a sustainable basis, from the energy sources available in the country.

The ever-growing environmental restrictions and the unquestionable proofs of radical weather changes in the planet impose new attitudes towards waste, at short term, and policies for the efficient use of natural resources, at long term. Therefore, the preparation of a National plan for power efficiency is as important and urgent as the plans for expansion of energy offer.

In this perspective, Brazil has been developing, since 1984, four major power efficiency programs: PBE—Programa Brasileiro de Etiquetagem (Brazilian Labeling Program), created in 1984 and coordinated by the Instituto Nacional de Metrologia e Normalização e Qualidade Industrial (INMETRO/MDIC) (National Institute for Metrology Standardization and Industrial Quality), of the Ministério do Desenvolvimento, Indústria e Comércio Exterior (Ministry of the Development, Industry and Foreign Trade); PROCEL—Programa Nacional de Conservação de Energia Elétrica (National Program for Preservation of Electric Power), of 1985; CONPET—Programa Nacional da Racionalização do Uso dos Derivados do Petróleo e do Gás Natural (National Program for Rationalization of Use of Oil and Natural Gas By-Products), of 1991; and PEE—Programa de Eficiência das Concessionárias de Energia Elétrica (Efficiency Programs for Electric Power Lessees). On 17 October 2001, the Act 10.295 was enacted, which provisions on the National Preservation Policy and the Rational Use of Energy, and which provides other measures, which sets forth in its Section 2 that "The Executive Power shall set forth maximum energy specific consumption levels, or minimum power efficiency, of machines and power-consuming devices manufactured or traded in the Country, based on relevant technical indexes." The Decree 4.059, as of 19 December 2001, which regulates the Act, sets forth in its Section 2 The Managing Committee of Power Efficiency Indexes and Levels (CGIEE), managed by the Ministério de Minas e Energia (MME), and with representatives of the Ministério de Ciência e Tecnologia (Ministry of Science and Technology; MCT), MDIC; of the Agência Nacional de Energia Elétrica (National Electric Power Agency; ANEEL); of the Agência Nacional de Petróleo (ANP); and by the technicians of the afore-mentioned programs.

These experiences in Brazil towards the effort to rationally use power present significant results, both in the standardization point of view—all household appliances of the line bear, compulsorily, the Etiqueta Nacional de Conservação de Energia (ENCE) (National Power Preservation Label), with the indication from the most efficient product (range A) to the least efficient (range E) and the average yield per range—and in the power preservation line. As an instance, the gas-generated stoves traded in Brazil have had an average yield of 62.4% (range A), against an average yield of 52% considering a period of measurement of 8 years. Moreover, since 1984, the efficiency programs devoted to the final use of electricity produced total savings of about 42.5 TWh, equivalent to 11.8% of the total electricity demand (basis 2005), which is equivalent to 50% of the generation capacity of the Itaipu Power Plant in that year (Zimmermann, 2006). In the same line, in the last 2 years (2005/2006), PROCEL, in its several programs, accumulated an economy in power of 4531 GWh, equivalent to a plant of 1087 MW, considering the load factor of 56% and including 15% of the average losses in transmission and distribution (Procel/Eletrobras, 2006). In the same period, CONPET, with its programs in the transportation area, obtained a reduction in diesel consumption of 572 million liters, and the non-emission accumulated of 1.6 million tons of CO_{2eq}. These numbers refer to 34% of the country's circulating transportation fleet (cargo and passengers), for an average increase of 5% in the mechanical efficiency of vehicles. The goals for 2011 are to obtain a reduction of 1.97 billion liters of diesel and the non-emission of 2.92 million tons of CO_{2eq} (Conpet/Petrobras, 2006).

Recent estimates show the existence of an economy potential in the use of electric power, for the next 5 years, of 29.7 TWh, equivalent to 7.9% of the consumption (basis 2005). The major economy potential was identified in the industrial sector (30.9%), followed by the residential (25.25%), the trading sector (18.85%) and in public lighting (5.4%), by means of an autonomous preservation policy of the market focusing on the increase of the efficiency of machines and other equipment of about 5%, resulting from the technological evolution and of non-compulsory actions. On the other hand, if the articulated power efficiency policy is emphasized even more, with the Government creating new mechanisms and incentives for its implementation, Brazil may add additional savings of

Production Chain Activity Segments	Supply of Services			Supply of Goods
	Education Area	Technological Assistance Area	Applied Research Area	
Electricity Generation	▪ Qualification of medium level technicians, specialists in natural gas; ▪ Natural gas specialization course for engineers; ▪ Qualification of natural gas systems operators and maintenance personnel ▪ Qualification of thermal electric projects engineers and coordinators.	▪ Dimensional metrology tests; ▪ Pressure measurements from 0 to 1000 mbar, 1 to 150 bar and 0 to 0.022 bar. ▪ Temperature measurements in the range of 50 to 1000 °C; ▪ Gas flow rate measurements; ▪ Technical-economic viability studies; ▪ Energy performance optimization studies ▪ Boiler burners combustion tests; ▪ Equipment certification.	▪ Burner technology and geometry; ▪ Research into alternative materials for thermal insulation; ▪ Combustion and heat transfer processes simulation; ▪ Studies for the substitution of fuels aggressive to the environment.	▪ Boilers; ▪ Recovery boilers; ▪ Heat exchangers; ▪ High performance burners; ▪ Electricity generators; ▪ Cogenerators; ▪ Special valves; ▪ Intelligent meters; ▪ Automation systems; ▪ Flow directors; ▪ Safety devices.

Chart 2. Goods and services to be offered to the Brazilian natural gas industry.

around 5% of the national consumption (basis 2005) for the next 5 years, which is equivalent to an operation of a "virtual plant" of 6.4 GW. The said effort would result in a potential economy equivalent to 13.3% of the consumer market (Procel/Eletrobras e Abesco, 2006). Considering a long-term period (up to 2015), the potential savings of energy including the oil and gas sources would rise up to 75.82 TWh with major potential in the industrial sector (60%), followed by the trade sector (21%), residential (15%) and public lighting (4%) (Zimmermann, 2006).

At last, Brazil, when incorporating for the first time the matter of power efficiency in its PNE 2030—National Power Plan 2030, shows its commitment with the environmental issues and restates that power efficiency is a task for the state (Ministério de Minas e Energia/Empresa de Pesquisa Energética MME/EPE, 2007).

8. Natural-gas-powered thermoelectricity: goods and services infrastructure

To definitively make the implementation of natural gas power plants viable in Brazil, it is considered important that the country has at least a minimally developed natural gas goods and services industry. Considering that the insertion of natural gas into the Brazilian Energy Matrix is a new factor, the development of a capital goods and services segment is necessary, so that investors find support for their initiatives and there is a larger percentage of national content in the plant projects.

A study carried out by Alonso (2004) identified which goods and services would be essential for supporting projects related to the application of natural gas in the industrial, commercial, urban and automotive gas, and energy generation segments. Chart 2 lists these goods and services in the case of thermal electric projects.

The qualification needs of the personnel listed in Chart 2 can be supplied by a joint effort involving the official technical schools (government professional schools), the National Industrial Training Service (SENAI)[8] and the universities. In a certain manner this effort has already begun, but it still needs to be emphasized. Various MBA programs in Energy Planning are being offered by Brazilian universities, and personnel for the management of thermal electric projects are already graduating in the country.

The need for developing goods or matters related to the applied research is still at a very early phase. Although the Brazilian capital goods industry has a reasonable manufacturing capacity, there was a loss of skills because of a lack of demand for equipment and services in the 80s and 90s, when the economy was basically driven by the investments of the large state-owned companies. The same applies to some engineering services, such as economic studies, energy performance optimization studies or even thermal projects development (basic and detail design). A government program called PROMINP—Mobilization Program for the Petroleum and Natural Gas Industry (Ministério das Minas e Energia (MME), 2005), linked

[8]The National Industrial Training Service (SENAI) is a private organization founded in 1942 by an initiative from industrial sector companies. An integral part of the National Industry Confederation (CNI) and the State Industrial Federations, SENAI supports 28 industrial areas by means of training human resources and laboratory, applied research and information technology services.

directly to the Ministry of Mines and Energy, is taking care of recovering the engineering and innovation skills for Brazilian industry.

Metrology-related technological assistance services are being prepared by the implementation in Brazil of a Network of Natural Gas Technological Centers, linked to the Gas Technologies Center (CTGAS[9]) (Alonso, 1999), a research institute based in Natal, in the state of Rio Grande do Norte. The State of São Paulo Technological Research Institute is also offering metrology services, especially in natural gas flow rate measurement for billing purposes.

9. Conclusions

The Brazilian electricity system is sustained, and will continue to be predominantly based on hydroelectric generation. Experience of how the system functions based on statistical and real data accumulated over more than 70 years[10] demonstrated the need to plan a thermal power sector, to improve the reliability level of the system as a whole, avoiding the risk of a shortage in supply from its principal source. The existence of dry hydrological cycles compromises seriously the ability to serve the demand for energy, as was seen in the 2001 crisis with the entire country submitted to drastic rationing.

In the same manner, the deficiencies and restrictions for transmission, over the electricity network, can be minimized with the installation of thermopower plants at points which improve its operation, optimizing the electrical conditions for relaying power.

The choice of implementing a natural gas thermopower sector, supported by the Brazilian reserves and by the long-term contract for the supply of Bolivian gas, represents a safe, reliable option and is in accordance with the ever-growing environmental requirements, principally in relation to the environmental impact of reservoirs provoked by the creation of dams. If there were to be problems originating from the supply of natural gas, there will always be the possibility of transforming the thermal power plants into dual-fuel plants, to use diesel oil or fuel oil, but which does not mean that the consumption of alternative products other than natural gas should be divorced from the worry about the sustainability of the environment.

As shown previously, there is a trend in Brazil towards renewable energy, and the perspectives for the use of biodiesel, ethanol and biomass as an energy source in many industrial applications are encouraging. Nevertheless, in regard to electrical energy generation, these alternative sources are at present non-competitive as compared to natural gas. Taking into account that the Brazilian dispatch energy model runs optimizing operational costs, thermal plants driven by biofuels will not be considered a priority to complement the hydraulic generation. Nevertheless, biofuels may be considered an alternative for power generation in Brazil in the long term.

The efforts toward power efficiency in Brazil will surely continue not only from the standpoint of Government Institutional Programs but also from the perspective of several initiatives being developed in private enterprises operating in all economic segments. The severe rationing that affected the country in 2001 raised a consciousness of the importance of power efficiency in the population as a whole, and significant results have been achieved since then in the field of household appliances manufacturing, domestic illumination and mechanical efficiency of vehicles (see item 7). Industrial power efficiency has been growing too in Brazil since the 80s when the Government launched the four major power efficiency programs still in effect today (Procel/Eletrobras, 2006). The economy potential of 29.7 TWh in the use of electric power at a short term is equivalent to 7.9% of the total 2005 consumption. Looking to a broader horizon up to 2015, the whole potential for energy savings including electrical energy and oil and gas sources would rise up to 75.82 TWh (see item 7). The incorporation of the theme of power efficiency in the PNE 2030 (National Power Plan 2030), the official document issued by the Ministry of Mines and Energy for the energy usage in Brazil, shows clearly that this is a task for the state and a matter of utmost importance for a developing country.

This is all related and aligned with the usage of natural gas turbines, because there is always the possibility of technological performance advances, which practically does not occur with hydraulic turbines, conferring another horizon of possibilities for improved profits. Taking into account such an advance, and that it is almost impossible to implement new hydroelectric plants in the country because of construction time and environmental impacts, the amount of necessary capital investment in thermal electric plants becomes a window of opportunity for private capital. Natural gas generation shall be consolidated as a safe option to guarantee the supply of electricity for Brazil in the coming years, which reinforces the role expected for this fuel to be, along with oil derivatives and electricity, the pillar of the Brazilian Energy Matrix.

[9]The Gas Technologies Center (CTGAS) is a research institute maintained in a partnership between PETROBRAS, a Brazilian oil and natural gas company, and SENAI. It is dedicated to supplying technological services and support for developing products for the natural gas industry. It is based in Natal, in the state of Rio Grande do Norte, in the Northeast region of the country. It operates 15 advanced centers spread throughout the states of Brazil. The centers are able to offer basic services to the natural gas industry in the areas in which they operate.

[10]The Ministry of Mines and Energy and Eletrobrás led the studies related to the behavior of the hydrological cycles in Brazil.

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