Hydroelectric, thermal and nuclear generation

Luiz Pinguelli Rosa

The electric energy problem

The debate on energy in the beginning of President Lula's second term in office became more intense, involving the Growth Acceleration Plan (GAP) itself, which was announced with great expectation to overcome the apathy in which the Brazilian economy had fallen more than a decade ago. Therefore, the success of GAP is important. Energy must not be a bottleneck.

The first sign of the problems that are in the root of the current debate was given in the beginning of the president's first term by the so-called Study Group for the New Structure of the Electric Sector (Genese), created in 2003 to aid the Superior Council of the Eletrobrás System (Consise), made up by the presidents of the federal generation companies. At that time Consise was assigned an important strategic role within Eletrobrás, defining lines of action of its companies, which unpleased many people.

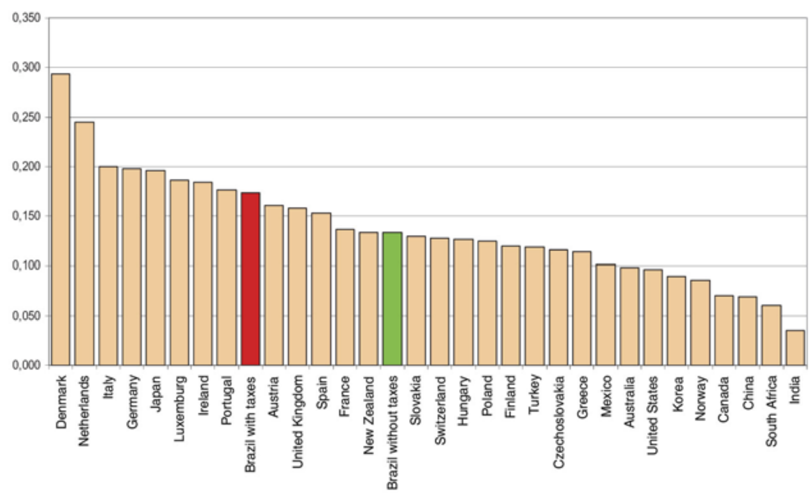
The emergency problems that were indicated included the market decline after the 2001 electricity rationalization, which produced an energy surplus in the short term and pulled the price down at the *spot* market, where the generation companies sold that surplus. By order of the regulation applied by the government, from 2003 on the federal generation companies (that belong to Eletrobrás), such as Furnas, had their contracts with the distribution companies, such as Light and Eletropaulo, progressively cancelled. Therefore, they had to sell their energy at the *spot* losing revenues and reducing their investment capacity. To give an idea of what that meant, Furnas sold hydroelectric power to the distribution companies according to a contract at R$ 80/MWh, while at the *spot* it only reached R$ 18/MWh. Some of that energy at the *spot* served to substitute contracted energy from thermal power plants, that remained turned off, since the National System Operator wouldn't dispatch them if there was an adequate level of water in the hydroelectric power plants' reservoirs. However, those thermal power plants that were turned off received as much as R$ 130/MWh according to the contracts that they had with the distribution companies. Furnas continued to produce energy with almost 100% of its capacity, with half of it being paid by contracts for approximately R$ 80/MWh, and half at the *spot* market for R$ 18/MWh, which resulted in an average of R$ 49/MWh. At the time I voiced my dissatisfaction with that situation which gave Eletrobrás a huge loss.

The issue of the free consumers that emerged now was also discussed then. They bought excessively cheap hydroelectric power when there was surplus. The free consumers, large industries that are energy intensive, currently absorb 30% of the Brazilian electricity and are out of the system covered by the concessionaries with high rates.

Finally, the introduction of the thermal power plants, originally anticipated by the Thermal Plants Priority Plan of Fernando Henrique's term, wasn't completely solved and today it unfolds in the problem of the natural gas that is not available for electricity generation, besides the inadequacy of the contracts. A second aspect related to that last issue is technical in nature: how to insert the thermal power plants in the Brazilian mostly hydroelectric system. For this to happen there must be a review of the very method used to define ensured energy, risk and cost of the deficit and the use of the aversion to risk curve due to hydrological variation.

The implementation of the new model and the energy auctions

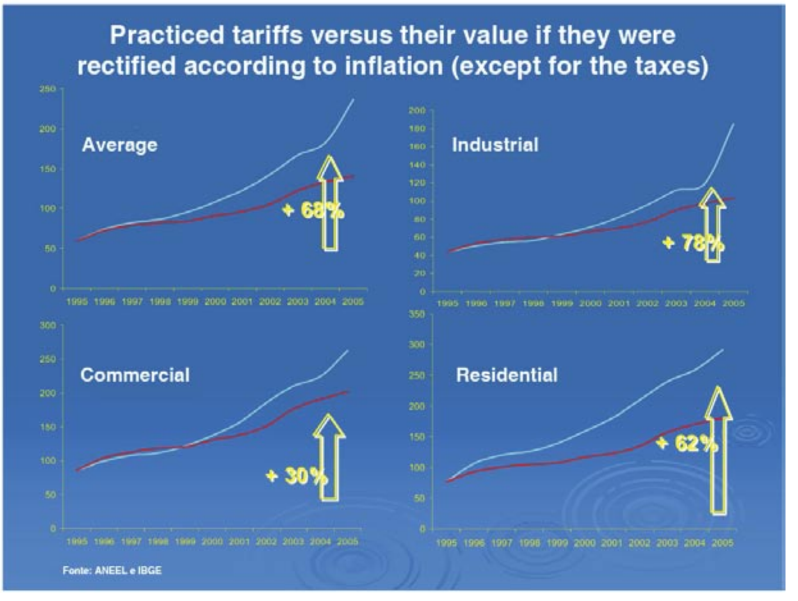
The result of the old energy auction in the electric sector that took place on December 2004 was symptomatic. Although that denomination is conceptually questionable, in the jargon of the new model of the sector old energy means energy produced by old hydroelectric power plants, the investment of which has already been paid off. I include myself among the advocates of attributing a lower price to that energy, consistent with the public service philosophy. Two goals must be kept in mind. The first one is to transfer to the consumer the advantage of the existence of old hydroelectric power plants, which last for many decades, unlike the thermal power plants.



Source: Roberto d'Araujo, Seminar at Fiesp, January 2007.

Figure 1 – Residential electricity rates (US$/kWh.)

In that aspect, the auction's goal did not reach the expected result. A study by Roberto d'Araujo, presented in a seminar at Fiesp on January 2007, shows that electricity in Brazil has become more expensive than in many rich countries, specifically than in those countries that rely heavily on hydroelectricity, such as Canada (Figures 1), and that it has been raising way above inflation in recent years (Figure 2).



Source: Roberto d'Araujo, Seminar at Fiesp, January 2007.

Figure 2 – Electricity rate (blue line) raising above inflation (red line) .

The other goal of the energy public service is to obtain some of the resources for the expansion of the service from the remuneration of the electricity company, since it is cheaper than to levy resources to interest that will have to be paid by the consumer in the next rate. That goal was harmed by the way in which the auction was done.

When we examine the old energy auction of December 2004, we can see that the privatized generation companies didn't sell much energy in it, unlike the federal ones, which sold it cheap. The fact is that the privatized generation companies were allowed to make contracts to sell energy to companies before the auction, which was denied to the Eletrobrás Group. It couldn't sell its papers and, therefore, was stuck with them. The example of Furnas is emblematic. In the old energy auction it sold for R$ 60/MWh. Furnas had contracts for energy purchase at much higher rates. One of them was with an Anglo-American thermal power plant – that didn't work for much of the time, but received R$ 130/MWh even without producing energy. Furnas also paid to the Spanish company Cien for power transmission from Argentina, which had no power to transmit. My opinion always was that those contracts had to be re-negotiated. Besides, Furnas bought power from Eletronuclear at a higher price than that of the auction.

Another problem was that the auction's contracts were for a period of eight years. In that period energy price is expected to rise, since the consumption growth depletes the energy surplus caused by the rationalization and by the measures adopted right after it. Bound to practice a low price in the long term, Furnas, Hydroelectric Company of the São Francisco River (Chesf) and Electric Centers of Northern Brazil (Eletronorte) lose potential revenue and their capacity to invest decreases, and the private sector will have to fill this space. Thus it is possible to understand the logic to keep the prices of the power produced by the state-owned companies low to permit them to charge the high price of private generation. In the past, the state-owned companies lost money selling power at a low price and they stopped to invest. That was an argument for the privatizations. In 2003, Lula's government reversed that. Are we taking the risk of repeating the cycle? In an interview to the Program "Roda Viva" on TV Cultura of São Paulo, on October 2003, I had stated that "no model that doesn't remunerate the state-owned companies will be viable and sustainable", is "to repeat the mistake of the dictatorship: for some time the state-owned companies produced cheap steel for the industry to profit".

Near the end of 2005, I published an article at *Folha de S.Paulo* which anticipated what happened in the other auction, that of the so-called new energy. Unfortunately, my prognosis turned out to be right when the auction took place. The new electric sector model, as it had been conceived by the working group that I coordinated at the Citizenship Institute, should implement a public policy with the goal to increase the energy supply to cope with the increase of the demand in an efficient manner. However, depending on the economy's growth, the situation might become dangerous in about two years from now. The period is short, since a hydroelectric power plant takes five years to be built while a thermal power plant needs three years. The only reason why a crisis has been avoided in 2007 is that there was pretty heavy rains in the beginning of this year. Some problems may hinder growth and still lead to very expensive energy, which the consumer pays for.

In the first auction for the building of electric power plants, in other words, in the new energy auction, it was expected that the supply growth should give priority to renewable energy, especially to new and cheaper hydroelectric power plants. But, from seventeen hydroelectric power plants in the first phase, the government only obtained environmental licenses for six of them, for a total of only approximately 400 MW of secure power. Since the environmental licensing process of a hydroelectric power plant is more complicated and takes longer (years) than that of a thermal power plant (few months), oil, diesel and coal power plants were enabled in the auction, besides gas and sugar cane bagasse, which are much better. Diesel generators were also enabled, for emergencies. Since the 2001 rationalization we have been paying for it in the "blackout" insurance.

With the goal to attract private capital, the Social and Economic Development National Bank (BNDES) vowed to finance 80% of the total value in fourteen years without requiring any corporate guarantee. But that was true only for private companies. Today, through GAP, that period was extended to twenty years. Since the auction limited the MWh price of new hydroelectric power plants at 116 reais, which the private investors consider to be low, those power plants had to be paid for by state-owned companies with their own resources. However, the companies belonging to the Eletrobrás Group, the greatest generation and transmission company in South America, were left with unfavorable conditions regarding future revenues to invest. They were induced to sell the so-called old energy, the one from the old power plants, at a low price.

As far as the thermal power plants are concerned, some of them pollute the atmosphere too much and produce expensive energy due to the fuel price. The criterion used in the auction was to select the thermal power plants with the best cost-benefit ratio, which takes into account both the investment cost and the additional cost when the plant operates using fuel. That latter cost depends on for how long will the plant be operated within a period of twenty years. That will depend on the availability of hydroelectricity in the system, since the thermal plants operate as a complement. It makes no sense to burn fuel, which is both fossil and expensive, if there is water to turbine in the dams. Therefore, it is necessary to estimate the actual operation time.

The problem is that there is some uncertainty in that estimate. In an optimistic prediction, the thermal plant will remain turned off for most of the time, serving to provide safety to the system in the case of lack of rains. In this case, it is irrelevant in the auction if the plant is inefficient and if it consumes too much expensive fuel when it operates. The most important thing is the investment cost. The emergency thermal plants that use oil or diesel have already been paid off, even though, when they produce energy, its cost may reach 350 reais per MWh, while efficient plants that use natural gas can produce electricity at a cost of 130 reais per MWh, but they have a greater investment cost. In the optimistic prediction of abundant hydroelectricity, the less efficient plants won the auction. If that prediction is not confirmed later on, the thermal plants that win the auction will work for a longer period of time and the consumers will have to pay for a very expensive energy.

In short, Brazil, that is proud to have a clean energy mix, moves from hydroelectricity to low efficiency thermal plants. And, successively, it will move from natural gas – which barely began to be used – and from sugar cane bagasse – which could be used more often to produce electricity to the network – to oil, diesel and coal – which are more expensive and more pollutant besides contributing more for the global heating of the Earth, discussed in the United Nations conference on climatic change.

Thermal generation and the natural gas issue

In the turn from 2006 to 2007, there was a growing concern about a new blackout. But the current situation is different from what happened in 2001. The rains in the end of 2006 and in the beginning of 2007 were favorable. In the reservoirs of the hydroelectric plants the average water level is above that which is determined by risk aversion curve, defined as the limit to be avoided. If the rains decrease and/or the economy grows and consumption increases, the thermal plants will be turned on to avoid a high rationalization risk in the short term. But many of them don't have gas available. That's the question. I warned that in articles, in a meeting of the Economic and Social Development Council, to which I was invited by Minister Tarso Genro, and in my intervention on a meeting of the scientific community with President Lula.

The existence of the problem was acknowledged when the National Electric Power Agency (Aneel) took off many thermal plants from the operation plan, since they had no gas available to operate, according to Petrobrás. Before that, when the National System Operator determined that a set of thermal plants should be turned on, less than half worked. The resolution by Aneel showed that the risk of an energy deficit is much higher than it was estimated. There was a controversy with the Ministry of Mines and Energy and it was established that the thermal plants should operate for a limited time as a test. The result of the test was worse than expected. Petrobrás was asked to re-manage the gas from other users.

Petrobrás informed that: (1) there is no gas available for those thermal plants to operate for a longer period of time; (2) close to 3 thermal GW have not been contracted; (3) there are problems in the new model due to the free consumers. They bought too much cheap hydroelectric power that the generation companies had left out of the contract due to regulation. The free consumers, which are large energy intensive industries, absorb 30% of the Brazilian electricity and are out of the system served by the concessionaries with high rates. If the risk increases, they will have to pay more in the new contracts.

A thermal power plant in the Brazilian system operates as a complement to the hydroelectric ones. It makes no sense to spill water while gas, which is fossil and imported, burns. However, when the average level of the reservoirs drops too much, the thermal plants must be turned on, if there is a lack of new hydroelectric plants. There is the problem of the usual contracts, in which there is payment for the use of gas without interruptions. Even before the Bolivian crisis, Petrobrás considered importing liquefied natural gas through ships, which may be interrupted according to the need.

The problem is that it takes a long time to establish a re-gasification plant. There is thought about adapting thermal plants to use two kinds of fuel, with the possibility to use diesel or other fuels instead of gas. But they are much more expensive.

When the new model was established, privileged contracts were maintained. The thermal plants were introduced without taking into account the Brazilian hydroelectric system and the energy auctions lead to coal and diesel thermal plants, which are both expensive and pollutant, besides emitting more greenhouse gases.

The rise of the international oil price affects natural gas and, therefore, electricity generation – even though today the share of oil in the world economy is lower than at the times of the shocks in the 1970's. In a global scale, that share in the costs of the products in general is half of what it used to be. The current price of US$ 50/barrel is much lower than what it reached during the second oil shock in 1979, in constant and rectified dollars.

Hydroelectric generation

The Latin American population is 7% of the global one, while primary energy consumption in Latin America is 4.7% of the world consumption, which demonstrates unevenness. Now, if we take the primary energy sources into account, the Latin American share varies:

- 5.8% in oil;
- 4.0% in natural gas;
- 0.8% in nuclear;
- 21.1% in hydroelectricity.

Therefore, the presence of nuclear electricity generation in Latin America represents less than 1% of nuclear generation worldwide. It is limited to Brazil, Argentina and Mexico. At the same time, that of hydroelectricity is higher than 20%. Brazil, Venezuela and Peru are among the ten countries with the greatest hydric resources in the world (Table 1).

Table1 – Hydric Resources

Countries	km^3/year
Brazil	8,2
Russia	4,5
Canada	2,9
Indonesia	2,8
China	2,8
EUA	2,0
Peru	1,9

Source: FAO, ONU, 2003

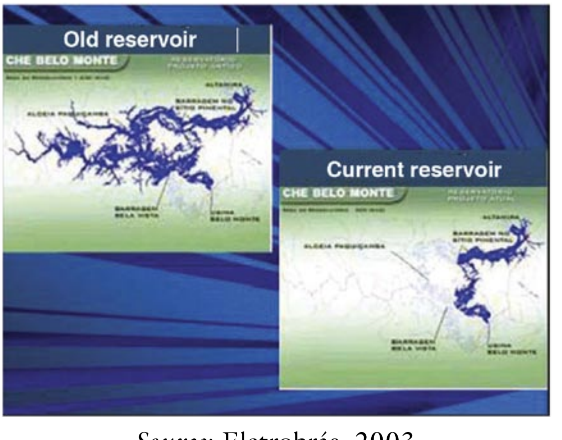
As can be seen on Table 1, Brazil is the country with the greatest hydric resources in the world. But Brazil is not the first one in terms of their use, but the fourth (Table 2). Few people know that. We have unused hydroelectric resources in the same proportion as the countries such as the United States. Brazil uses approximately 25% of its hydroelectric potential; the United States uses almost 80%.

Table 2 – Installed capacity of hydroelectric plants

Countries	MW
EUA	79,5
Canada	66,9
China	65,0
Brazil	57,5
Russia	44,0
Norway	27,5
Japan	27,2
France	25,3

Source: Roberto D'Araujo, Seminar on Energetic Strategies, 2004

Hydroelectricity depends on meteorology. Of course, once in the reservoirs, water enters the market. The problems of hydroelectricity due to the environmental issues and to the movements against the great dams lead to the tendency of abandoning that power source. The government must negotiate democratically with the environmental movements. Due to environmental impacts, the size of the areas flooded by future dams in Brazil must be reduced, such as in the case of Belo Monte. Eletronorte reviewed its project when I was at Eletrobrás, substantially reducing the area affected by the reservoir. Although power is lost on the other hand, that might be the price to be paid to minimize its impacts.



Source: Eletrobrás, 2003

Figure 3 – Reduction of the Belo Monte project.

Figure 4 shows the Madeira River project. There are a few technical problems such as the great flow variation at Belo Monte and Madeira, both without a regulation reservoir. For the power from those plants to be firmed, thermal plants can be used, in which case they would operate during the low flow months. Another problem is the use of bulb-type turbines at the Madeira River, with a problem of electric stability, which can be solved by using continuous current in the long-distance energy transmission.

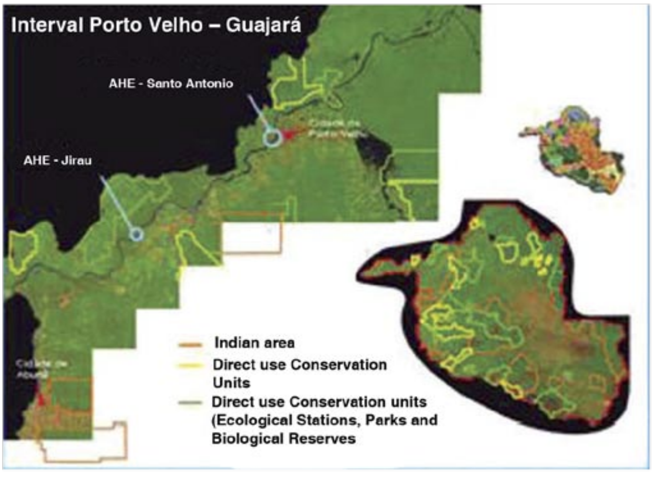


Figure 4 – Madeira River Project (Jirau and Santo Antônio plants).

Tables 3 and 4 compare hydroelectric, fossil and nuclear thermal generation, and between the three great projects that are being discussed in the government: Belo Monte, Madeira and Angra III.

Table 3 – Comparison between electricity generation forms

	Hydro	Thermal	Nuclear
Investment per kW	High	Lower	Very High
Fuel cost	Very High	Low	
O & M cost	Low	High	Very High
Energy cost	Low	High	Very High
Transmission line	Long	Shorter	Shorter
Building time	Long	Lower	Long
Life time	Long	Small	Medium
Job generation	High	Lower	Medium
Environmental impact	Reservoir	Atmosphere	Radioactivity
Greenhouse effect	Lower	High	None
Import	Low	High	Medium
Return rate	Low	High	Low

Table 4 – Comparison between great projects being discussed

	Belo Monte	Madeira	Angra III
Investment	High	High	High
Energy cost	Low	Low	High
Transmission Line	Long	Long	Shorter
Environmental opposition	Big	Big	Small

Electricity generation from a nuclear source in Brazil

There is no consensus in Brazil concerning the nuclear option, but different points of view. However, an influence of the criticisms made in the 1970's/1980's to the nuclear programs of the military governments still prevail, specially regarding the Nuclear Agreement of 1975 with Germany, which intended to build eight reactors of 1,300 MW each until 1990 and to transfer the fuel cycle technology. Nuclebrás, a Brazilian state-owned company that joined the German Siemens, forming several subsidiaries in Brazil, was created for that reason. The facts justified the criticisms. Today, more than thirty years later, only one of the Agreement reactors, the one located at Angra II, has been built (Angra I was before, made by Westinghouse) and the *jet nozzle* technology to enrich uranium didn't work. Later the Navy successfully developed enrichment through ultracentrifuges within the project of a nuclear submarine, which includes the development of a small PWR reactor for naval propulsion, yet to be materialized. Enrichment technology is being transferred to the Nuclear Industries of Brazil (INB).

The debate almost stopped during the 1990's. Apparently those years were not very active in the nuclear area in Brazil, since the topic disappeared from the press. However, that is not exactly true. During President Collor's term the secret project of a nuclear test at the Cachimbo Air Base was eliminated, denounced by a report of the Brazilian Physics Society.

Brazil ratified the Treaty of Tlatelolco, for the de-nuclearization of Latin America, and implemented the Brazilian-Argentinian Agency for the Accountability and Control of Nuclear Materials (ABACC), an agency for mutual inspections of both Brazilian and Argentinian nuclear installations. President Fernando Henrique signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and Brazil integrated, along with Sweden and other countries, the coalition for a new agenda within NPT, for the reduction and later elimination of the military powers' nuclear arsenals. Unfortunately, that reduction is not taking place.

Nuclebrás and its subsidiaries were dissolved. Basically what remained were Nuclebrás Engineering (Nuclen) and the Heavy Equipment Factory (Nuclep) at Itaguaí. The rest was incorporated to INB, especially the installations for nuclear fuel production at Resende, to which the uranium enrichment technology developed by the Navy was transferred. Both INB and Nuclep belong to the Ministry of Science and Technology (MCT). Later, the operation area of the Angra Center was taken away from that company and was merged with Nuclen, which originated Eletronuclear, belonging to Eletrobrás. That was done during Fernando Henrique's term aiming at the privatization of Furnas, suspended in the Lula's term.

When Fernando Henrique was the President it was decided that work should be resumed with the conclusion of Angra II. The cost of US$ 500/kW initially estimated in 1975, raised to more than US$ 4.000/kW. Angra II was the only reactor of the Agreement with Germany to be concluded until today. Its construction took more than twenty years to get ready. Eight reactors were expected to be working by 1990 and there was an estimate of no less than fifty in the year 2000, besides the nuclear fuel cycle.

President Lula's government resumed the issue of nuclear energy with the decision whether to build Angra III or not. That would be the second reactor predicted by the Agreement and much of its components was imported from Germany and has been stocked for decades in Brazil. There are almost 700 million dollars worth of Angra III equipment stocked, but to finish the work it will be necessary another 1.7 billion dollars, about half of which would be funded by the French who currently control Siemens - German nuclear.

From the energy cost point of view we shall only reckon that remaining 1.7 billion dollars for decision purposes, since the 700 million are basically irretrievable, even if there is a residual value to the equipment. Some of it can be used as supply for the maintenance of Angra II and some of it for an occasional sale. A few years ago I participated, along with Maurício Tolmasquim, the current President of the recently created Energetic Research Enterprise of the Ministry of Mines and Energy, of a study group in the Coordination of the Graduate Engineering Programs (Coppe) that compared the cost of nuclear energy to a possible hydroelectric plant and to a future thermal plant. Hydroelectric power is the less expensive one, followed by the thermal and the nuclear ones. When we compare the two latter power sources there is great sensitivity regarding the return rate (very high in the private thermal ventures, more than 15% per year and, in general, lower in the federal hydroelectric and nuclear ventures), as well as regarding the future price of natural gas. That can be lead by the raise of oil in the world market, which is currently close to US$ 50/barrel, after going beyond the level of US$ 70/barrel in 2006. By the way, we should recall that the energy price of some gas thermal power plants contracted by the private distribution companies, which pass it on to the consumers' lighting bill, is much higher than the Eletronuclear rate.

However, a chronic financial problem of Eletronuclear still remains: an unpayable debt of 1 billion Euros and another sum in reais or in dollars left for Eletrobrás, which has been paying its interests. Without solving this problem it is hard to find a healthy financial equation for the Angra III venture that might demand, if it comes into being, resources from BNDES, from the French and from private capital to minimize resources from Eletrobrás, since there are other works of great priority for the expansion and the operation of its companies – currently responsible for most of the generation, which is basically hydroelectric, from Itaipu to Tucuruí, and of transmission in Brazil. At that point there is a direct obstacle to the entrance of private capital, since nuclear energy is a monopoly of the Union, but a kind of mirror company could be used that would get the energy from Angra III, in the same pattern Furnas used in the Serra da Mesa hydroelectric plant. That is possible, but is there enough private capital for that?

From the environmental point of view, today nuclear energy has the advantage not to emit greenhouse gases. The thermal plants emit a lot of carbon dioxide using fossil fuels such as coal, oil and natural gas. Even though the emissions by hydroelectric plants were considered to be negligible, studies that my research group at the International Virtual Institute for Global Changes of Coppe-UFRJ made in the reservoirs, in cooperation with the limnology group from São Carlos, showed that they emit both methane and carbon dioxide, though in general it is much less than the thermal plants do.

In a meeting of the National Environmental Council (Conama) by the end of Fernando Henrique's government, I rendered the debate on the resume of Angra III conditional to solving the environmental liabilities of Angra I and II. The replacement of the steam generators of Angra I was taken care of, facing obstacles, when I was the President of Eletrobrás and Zieli Dutra Thomé was the President of Eletronuclear. The second liability concerns the external emergency plan to evacuate, if necessary, the population that live next to the nuclear plant in case of a serious accident. I consider that plan to be insufficient. There should be a greater involvement of Armed Forces means. The last and most difficult issue to solve is the destiny of the reactors' radioactive waste. The ones with low and medium radioactivity may have a solution similar to the one adopted at Abadia storage yard, near Goiânia, where the material contaminated by the accident with the cesium 137 was sent. The worst are the high radioactivity wastes, which remain dangerous for thousands of years and there is no common solution for them in the world. In Angra they are well stored in swimming pools next to the reactors, but that solution is temporary even though it may remain while the reactors last, that is, up to twenty years. But it is necessary to study from now on what will be done afterwards.

I disagree that Angra III is crucial to justify uranium enrichment, which is currently being transferred to INB. The ultracentrifugation technology which the Navy developed for the nuclear submarine project (moved by nuclear propulsion) is expected to be used for Angra I and II. During the 1973 oil crisis the contract that ensured enriched uranium to

Angra I, which was being built at the time, was suspended. The jet nozzle technology for uranium enrichment bought by the Nuclear Agreement with Germany failed. Therefore, uranium enrichment has a strategic character for electricity generation at the Angra Central in the case of an international crisis.

If a decision is reached not to build Angra III, a way to avoid the loss of Eletronuclear's technical competence would be to divide it into a federal company for nuclear and thermal generation (joining it with the Company for Thermal Electricity Generation (CGTEE), which is a coal-fired generation plant belonging to Eletrobrás) and another one for reactors technology, that one being within the scope of the Ministry of Science and Technology, joining in it teams that were formed in the nuclear submarine project. The latter would provide support to operate the reactor and would develop the prototype of an advanced reactor, towards the intrinsically safe ones that are objects of study in the United States, in Europe and in Japan. The small reactor designed by the Navy could serve as a starting point. As an example, South Africa has developed a small reactor concept. A partner for Brazil could be Argentina, which can use Angra I and II used fuel, provided it was re-packaged, in its natural uranium reactors.

In the campaign that elected Lula as President of the Republic, Souza Barros and I met with him at the Citizenship Institute so we could talk about the nuclear weapons issue. I disagree that, upon enriching uranium, the government may be thinking about enabling Brazil for nuclear weapons, as was suggested in some international publications, when the United States pressured to include additional obligations in the international inspections in the Brazilian uranium enrichment installations. There is no legal basis at all for that, since Brazil carries out to the letter its obligations under the Treaty on the Non-proliferation of Nuclear Weapons.

Technological perspectives of nuclear electricity generation

The world situation can be summarized as follows. There are no new reactors being built in the United States, which, despite that fact, are extending the life time of their reactors and have voiced its intention to build the so-called advanced reactors. Similarly, there is no reactor being built in France, which had an intense nuclear program until not long ago. In Europe, at the moment, there is only one nuclear reactor being built in Finland. The countries that currently have important reactors programs underway are China, Japan and South Korea. Figure 5 shows that in the last few years the nuclear reactors installed capacity didn't grow substantially, although the derivative is positive. Figura 6 shows nuclear electricity generation by countries.

The commercial nuclear reactors in the world use fission produced by very slow neutrons. Since the neutron produced by fission is quick, we have to moderate it, reducing its speed before it reaches another nucleus. For that to happen we make it collide with atomic nuclei of a moderator. The simplest moderator is water, because its molecules (H_2O) contain hydrogen (H). The best way to make a particle lose energy in an elastic shock is to make it collide with another one with the same mass, such as occur with the balls in a game of pool, in which, sometimes, one of them lose all its speed and remains still after the shock, transferring its kinetic energy to the other one. Since the

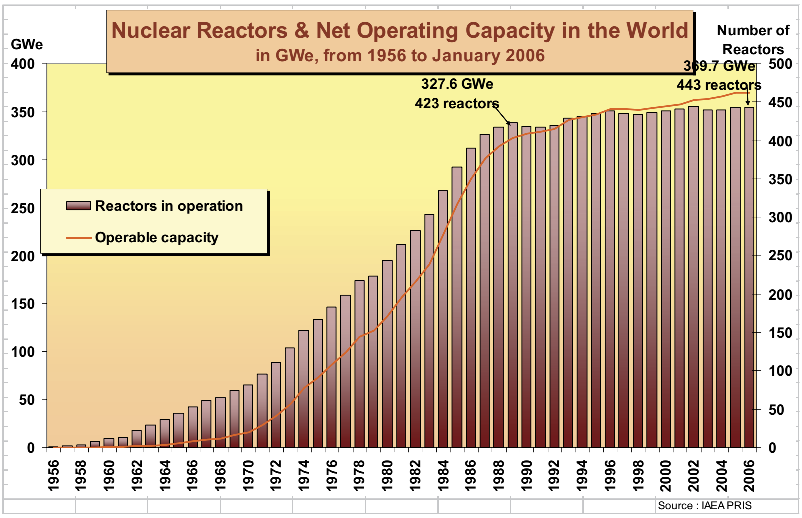


Figure 5 – Nuclear energy in the world – The figures for existing reactors (see the axis on the right) are given by the bars in each year and the operable capacity (average power at the axis on the left) is given by the red curve.)

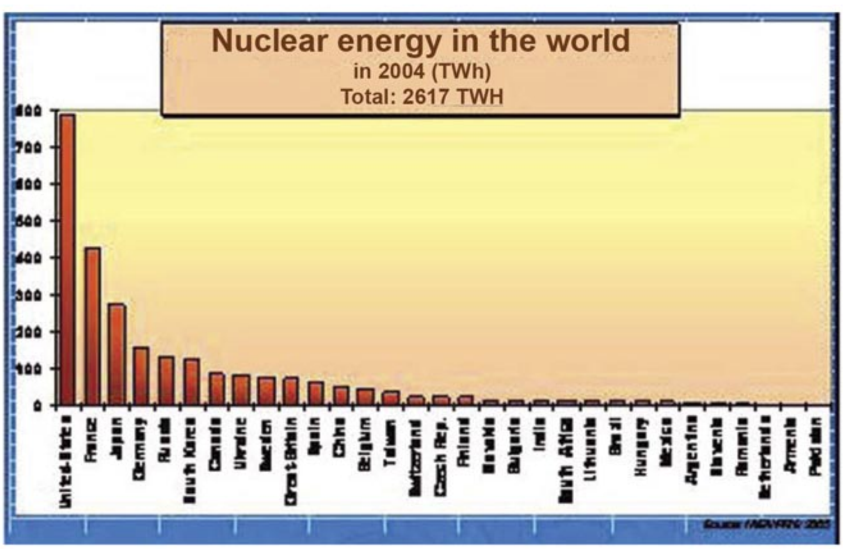


Figure 6 – Nuclear energy by country.

neutron and the proton have the same mass, hydrogen, from that point of view, is the best moderator, since its nucleus has only one proton. But there is a probability for the neutron to join the proton, forming a nucleus of deuterium, a hydrogen isotope.

So many neutrons are lost that, in a reactor which uses water as a moderator, it is impossible to form the critical mass of natural uranium for the fissions to sustain themselves – in other words, the minimum mass for a balanced chain reaction to happen, in which for every absorbed neutron another neutron is produced. To understand that, it suffices to consider that natural uranium has two uranium isotopes[1]: one (called U-238) with a mass which is equal to 238 atomic mass units and the other with 235 (U-235). The probability for fission to occur in U-235 when it is stroke by a very slow neutron is very high – for that reason it is said to be fissile. But the percentage of U-235 in natural uranium is only 0.7%, while the remaining 99.3% are nucleus of the U-238 isotope.

To use water as a moderator it is necessary to enrich the uranium, increasing the percentage of U-235 to at least 3%. That combination defines a technology – that of the enriched uranium reactors and water (LWR = *Light Water Reactors*), that split into two others: BWR and PWR. The technology of the boiling water reactors (BWR = *Boiling Water Reactors*) was developed by GE. The pressurized water reactors (PWR = *Pressurized Water Reactors*) currently dominate the world market and were developed by Westinghouse (Angra I) and adopted by Siemens in Germany (Angra II) and by the French company Areva (previously called Framatone), which currently owns Siemens-Nuclear.

PWR technology was totally funded by the North American State for nuclear submarines in the 1950's, right in the midst of the Cold War against the Soviets and that is why it had such a great advantage when it was adapted for electricity generation. In the beginning, the enrichment technology wasn't available neither to the Europeans nor to the Canadians – having been secretly developed by the Americans during the nuclear bomb project used at the end of World War II. That is why they opted for the use of natural uranium with another moderator, that doesn't absorb neutrons. In the order of merit comes heavy water, in which hydrogen is substituted by its isotope deuterium (D_2O) and carbon (C), used in the form of graphite. France and England developed the graphite reactors technology, which were also used in the former Soviet Union – such as the one in Chernobyl, which had an accident in which the graphite was burnt –, while Germany and Canada chose heavy water. Later, the first three countries changed to PWR, but Canada remained with the natural uranium technology and heavy water (Candu), imported by India and Argentina – which has two heavy water reactors: one by Siemens and the other by Candu.

There is yet another reactors technology that was considered to be very promising but presented problems – that of the regenerating reactors, that use highly enriched uranium and plutonium (isotope Pu-239) with quick neutrons, without any moderator. Their advantage is that they convert the majoritarian isotope of natural uranium, U-238, into Pu-239, which is fissile, just like U-235. The U-238 nuclei absorb neutrons, producing the isotope U-239 that changes into Pu-239, with the emission of radioactive particles. That conversion takes place in small quantity in the reactors with a moderator, but in the regenerating ones it is so high that it allows for the conversion of all the U-238 into Pu-239.

With the current technology, only a small part of the uranium found in nature is used. That is the reason for reprocessing the used nuclear fuel, to extract from it the rest of the uranium and of the plutonium. The regenerating reactors were developed in France, which built the Phoenix and Super-Phoenix reactors, but they didn't become commercial due to their high costs and to technical problems.

At the moment the main way for the advance of the reactors technology is to increase safety against serious accidents. The most advanced concept is that of intrinsically safe reactors – but they are still far from being carried out. Today the most realistic ones are the projects of advanced PWR and BWR reactors, such as the ABWR (*Advanced Boiling Water Reactor*) and the AP-1000 (*Advanced Passive Reactor*) in the United States. In Europe, the EPE (*European Pressurized Reactor*) project is being developed. Only as an example, Figures 7 and 8 provide a view of the ABWR and of the AP-1000 reactors. Both remain as projects.

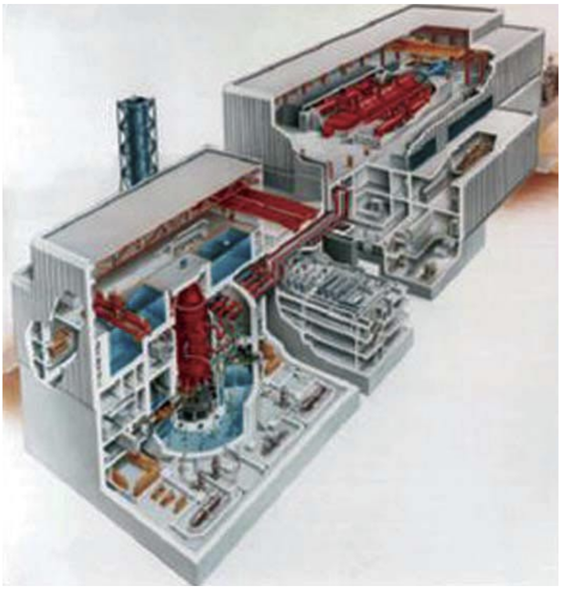


Figure 7 – ABWR advanced reactor.

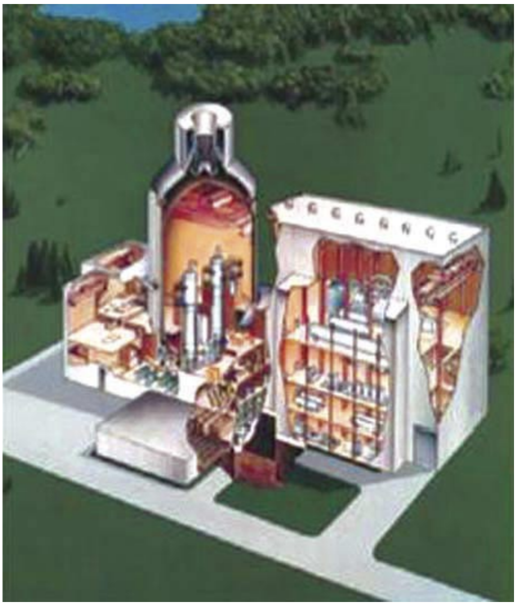


Figure 8 – AP-1000 advanced reactor.

The electricity generation alternatives

The government must give more attention to the renewable sources, among which is hydroelectric generation, even though it must acknowledge its environmental problems, including emissions of greenhouse gases measured by Coppe and by USP/São Carlos (Figure 9), which was the theme of a recent meeting in Paris. When I was the President of Eletrobrás, the company assumed the compromise to buy energy from wind and biomass power plants as well as from small hydroelectric plants of the Program for the Incentive to the Alternative Sources of Electricity (Proinfa), for a total of 3.3 GW, and investments were made to double Tucuruí, in the two new turbines of Itaipu and in the Peixe Angical hydroelectric plant in a partnership between Furnas and Energy of Portugal (EDP). But the environmental rules must be obeyed. It is the government's job to convince society of the quality of the projects.

There is a research and development effort about alternative sources going on in the universities, in the research centers, such as the Center for Electricity Research (Cepel) and the Petrobrás Research Center (Cenpes), and in companies, such as the Energetic Company of Minas Gerais (Cemig), Eletronorte and others, involving biomass, solar energy, the use of urban and agricultural residues, energy from the waves and the tides and from hydrogen. However, there is a clear need for a coordinated action to unite efforts in some cases, such as the fuel-powered battery, concentrating resources from the very disperse Sectorial Funds. That also has to do with the technological innovation issue.

A concrete example that was discussed at the Brazilian Energy Congress is the need to design the propellers of the aeolic generators according to the characteristic of the winds that prevail in the country, constant and with medium intensity, while the propellers used today, including those produced in Brazil, are designed according to the wind regime that prevails in the Northern hemisphere, which are more intense and less constant. Another example is the original project presented of an electric generator that uses sea waves that is being developed by the Ocean Engineering Department of Coppe (Figure 10) with the support from Eletrobrás. It will be implanted for testing in Ceará. A third case is the project of a thermal power plant, joining natural gas and the burning of urban garbage (Figure 11) or biogas from sanitary embankments, which is being studied with the support from Petrobrás, for distributed generation. It will be tested at the campus of Federal University of Rio de Janeiro (UFRJ).

Figure 9 – Greenhouse gases emissions measurement in hydroelectric plants made by Coppe-UFRJ and by USP- São Carlos.

Figure 10 – Electricity generation from sea waves (reduced model from Coppe).

The "Light for everyone" Program of the federal government is very important, since it promotes the universalization of electricity for the population, involving the state governments, the companies of the Eletrobrás Group and the private and state electric distribution companies. Some issues

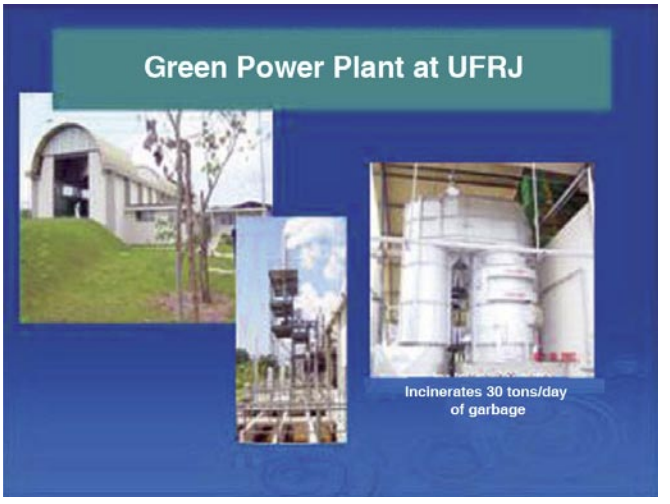


Figure 11 – Electricity generation with urban garbage at UFRJ.


Figure 12 – Biodiesel plant of the IVIG- Coppe-UFRJ (Project of electricity generation from palm oil in Pará).

were raised in an International Seminar that took place in Rio in 2006 about "Alternative energy sources for the North region".

There are difficulties to meet the goal of the "Light for everyone" in the North region, attributed to the complexity of the network extension where the population is very disperse in the Amazon forest. In the North region there exists a great amount of diesel generators and Manaus still depends on fuel oil to produce electricity while the gas pipeline is being built to substitute it for natural gas. The subsidies that the consumers pay in the lighting bill, through the Fuel Compensation Account (CCC), reached almost 4 billion reais in 2006. The isolated systems of the North region are a laboratory for the alternative energy sources. Coppe's Virtual Institute (IVIG) developed a biodiesel plant with support from the Studies and

Projects Fund (Finep) (Figure 12) that will be installed inside a container and shortly will be transferred to Pará, where it will process palm oil producing biodiesel to be used as an experience in a diesel generator of the Pará Electric Company (Celpa).

Finally, one must observe that the maintenance of the energy intensive development model is always under consideration. Thus, the need for an energetic policy also directed towards the demand side has been discussed, aiming at the increased efficiency of the equipment and the rationalization of their use, even in the residential sector, without denying in that manner the right of a great portion of the poorer population to increase its consumption, given the huge existing disparities.

Note

1 Isotopes are atomic nuclei with the same amount of protons and different amount of neutrons. The U-238 uranium isotope has 92 protons and 238 – 92 = 146 neutrons, while the U-235 has 92 protons and 235 – 92 = 143 neutrons. Since the chemical properties depend on the amount of electrons (equal to that of protons), U-235 have the same chemical characteristics as U-238, but its nuclear properties are different: U-235 have a high probability to undergo fission if it is reached by a slow neutron.

Abstract – The situation of electric energy generation in Brazil is presented here, showing the problems in the implementation of the new model for the Power Sector, as well as in the inclusion of thermal plants in a very big hydroelectric system. Environment issues are considered, in particular the greenhouse gas emissions. The article pays attention to the possible construction of new nuclear reactors in Brazil. It is pointed out the importance of energy conservation and of using renewable energy sources.

Keywords: Electric energy, Natural gas, Hydroelectric power plants, Thermal power plants, Nuclear energy.

Luiz Pinguelli Rosa is full professor of Coppe/UFRJ, graduate coordinator for Energetic Planning of Coppe, master in science in Nuclear Engineering and PhD in physics, member of the Brazilian Academy of Science and executive secretary of the Brazilian Forum on Climatic Change, former member of the Intergovernmental Panel on Climate Change, former secretary-general of the Brazilian Society of Physics, former director of Coppe and former President of Eletrobrás.
@ – lpr@adc.coppe.ufrj.br

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