THE DEVELOPMENT OF
HYDROELECTRIC POWER TECHNOLOGY
IN BRAZIL

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Introduction

This report reviews the history of hydroelectric power (hydropower) in Brazil from the early 1920s to the present time and the involvement of the World Bank in the development of Brazil's hydropower sector. It examines both the overall development of hydropower design and engineering skills, and the institutional developments associated with World Bank lending. It was assembled by reviewing Bank documentation and literature and by interviewing Bank staff members.

Development of hydropower in Brazil may be divided into three periods: (1) the pre-1945 period influenced by the foreign financed and controlled power companies, (2) the 1945-1960 period, with significant World Bank lending and the spread of state-owned utilities, and (3) the post-1960 period of continued expansion and the improved coordination of the hydropower sector.

The conclusions of the report are that:

1) hydropower technical design and engineering expertise in Brazil was already well established when the Bank started lending. The Bank took little or no part in hydropower technology development;

2) the Bank played a significant role in developing planning coordination in the previously fragmented electric utility sector;

3) the Bank is taking an important part in encouraging the development of power supply to low income users.

1. A Brief History

Brazil is a country of great hydropower resources, a large part of which are located within or near the industrialized and more developed areas in the south-central region. Much of this potential exists on rivers rising on the high escarpment along the coast of the Atlantic Ocean, several hundred miles on each side of Rio de Janeiro. These rivers flow inland before reaching the ocean far to the north and south.

Fossil fuels are scarce in Brazil. In the south, in the states of Rio Grande do Sul and Santa Catarina there are deposits of low grade coal of which some are used in the metallurgical industry and in small thermal plants in the area.

The main electric power developments have been in hydropower generation, with fossil fuel thermal plants complementing hydropower. A limited nuclear power program also exists. Hydropower remains the largest energy source, with large hydro sites developable in the areas requiring the greatest amount

1/ See Annex 1 - Bibliography
of power in the foreseeable future. These sites are generally low cost, relative to alternative energy sources in Brazil, and are also among the lowest cost hydro sites in the world.

The exploitation of these hydroelectric resources may be separated into three stages:

1) The growth of large foreign financed and managed electric utilities up to about 1945.

2) The movement towards state or federal generating agencies in the period 1945 to the early 1960s.

3) The coordination of fragmented public and private utilities country-wide, from the early 1960s to the present time.

2. The Foreign Utilities

The origin of the electric utility industry in Brazil goes back to the turn of the century and its development parallels, to some extent, that in other areas of the world. As in the case of many Latin American countries, foreign capital was an important factor. The main development occurred in the south-central area which is the most highly developed part of the country, containing the most important cities, the bulk of industry, and a large part of Brazil's agricultural and other natural resources.

Up to the 1930s, the industry was predominantly investor-owned, and was allowed to develop freely. With the Constitution of 1934, new principles were set out, the intent of which seems to have been to put electric utility development and ownership in the public domain. A Federal law governing utility regulation was enacted as the Waters Code of July 1934. Since then, the advent and growth of publicly owned utilities, inflation, the political affairs of the country and the regulation of the utilities has greatly diminished the relative importance of the private utilities.

The Canadian-owned Brazilian Traction, Light and Power Company of Toronto was, and still is, one of the most important power utilities in Brazil, and remains the sole distributor for the Rio-São Paulo metropolitan area. Brazilian Traction, incorporated in 1912, has as its two major wholly-owned subsidiaries Rio and São Paulo Light. The company went to Brazil with the initial purpose of substituting power for animal traction in the urban transport systems of Rio and São Paulo. Brazilian Traction took advantage of the previously mentioned hydro potential of rivers rising behind the mountainous escarpment of Serra do Mar.

The development scheme of Brazilian Traction -- stemming from its Chief Engineer, Asa Billings -- was to divert these rivers backward at their headwaters, over the edge of the escarpment to generate electric power at the
The diversion schemes were realized in the period 1922 to 1945 by a complex system of dams, canals, pumping stations, and underground and surface generating plants. This system was expanded each time an increase in capacity was needed. Brazilian Traction was considered a major force in the development of Rio and Sao Paulo for two reasons. It created an abundance of power in the 20s and 30s, and it took a new and rapidly developing technology, hydropower, and made it fit aptly into the topography of south-central Brazil.

During this period, Brazilian Traction developed its own cadre of competent engineers. The economic advantages to the foreign-owned company accruing from using local engineers was recognized at an early stage. Dr. de Souza, professor at the Sao Paulo Polytechnic School and Manager of Brazilian Traction, together with Mr. Billings, trained and developed a group of competent engineers capable of organizing, designing, constructing and managing a modern hydropower undertaking in Brazil. These engineers later provided much of the technical hydropower expertise in Brazil, particularly in the joint ventures of Brazilian Traction with State-owned utilities.

In the pre-1945 period, another private utility, the American and Foreign Power Co., contributed to the development of the hydropower industry. Although not as significant as Brazilian Traction, its contribution to the development of Brazilian technology and engineers was very similar.

3. Federal and State Utilities 1945-1960

Federal and State-owned public utilities experienced their main growth after 1945 and by 1965 had reached an annual energy production greater than that of investor-owned utilities. Since they were the first utilities the latter had developed the distribution systems in the main cities and most developed areas of the country. As a result, they continued to own the bulk of the distribution systems, in contrast with the publicly owned utilities which sold power mainly at the wholesale level. This was changed as a result of the acquisition of the American and Foreign Power Company properties by Eletronobras, an agency of the Federal Government. Brazilian Traction and its subsidiaries, Sao Paulo Light and Rio Light, which are responsible for distribution of almost 50% of the energy in Brazil, today remain the only large investor-owned electric utilities.

Inflation from 1945 to 1960 had a great impact on the development of electric utilities, especially those in the private sector. The erosion of the real value of base rates by inflation was compensated for in part by special rate increases to offset specific cost increases. Regular increases to the investor-owned companies were virtually non-existent. As a result, the private companies were unable to generate money for expansion internally, or to raise adequate funds externally (with the exception of borrowing from international agencies). Their expansion was virtually halted. The distribution systems in Rio and Sao Paulo cities suffered particularly badly.

1/ Source: Eng. Macho de Campos, Professor at the Engineering Institute of Sao Paulo, in a tribute to the work of Asa Billings, 1949.
Although the public utilities suffered similar erosion of real rates, they had access to public funds and were able to expand their generating facilities substantially.

The movement toward government control of the electric power supply industry in Brazil began in 1948 with the formation of CHESF to develop the São Francisco River. COPEL was formed as the official power authority for Parana in 1954 and CELESC followed in Santa Catarina in 1955. In Rio Grande do Sul the Comissão Estadual de Energia Elétrica, which had been created in 1943, was converted to Companhia Estadual de Energia Elétrica (CEEE) in 1963. The movement was primarily one of state enterprise, with each of the states developing a separate and independently operated network. This was accentuated because the power systems of Rio Grande do Sul were operated at 50 hertz, whereas those of Santa Catarina and Parana (for example) used the national standard of 60 hertz.

USELPA of Sao Paulo and Parana was formed in 1953 with the immediate aim of constructing the 60 MW Salto Grande Hydroelectric Project on the Paranapanema River (Bank loan of $10 million). A second plant of 180 MW at Jurumirim received a Bank loan of $13.4 million. A third plant of 360 MW at Chavantes received a Bank loan of $22.5 million.

CEMIG was organized in 1953 by the State Government of Minas Gerais to carry out a state-wide electrification program. Although in the south-central region there are a number of independent utilities, CEMIG has been the major influence on generation and distribution systems in the area. It developed with a high industrial load. Its facilities are in an area with a large concentration of power-intensive metallurgical industries, some with their own power plants. It is the only state company in the south-central region to have taken on both generation and distribution, and it has been called one of the best-run enterprises in Latin America. CEMIG became a supplier of managerial expertise to the state power sector. The five major figures in the state power sector of Brazil were all members of the founding team of CEMIG. These people later formed the Furnas Company, which made the first major contribution of state generating facilities to the Rio-São Paulo area.

During this period, the design and construction of projects by both private and state utilities benefitted from the technical expertise developed by Brazilian Traction's earlier training efforts. A cadre of engineers existed within the utilities and in Brazilian consulting firms, complemented by specialists in foreign consulting firms, that supplied Brazil's hydropower manpower needs. Generally, smaller projects used entirely Brazilian personnel.

1/ See Glossary, Annex 3.

unless international competition was required by loan stipulations. On the larger projects, foreign consultants worked in association with Brazilian firms. The limiting factor tended to be not the availability of design and engineering skills, but the availability of managerial, planning and financial capabilities. The cancellation of Bank Loan 64 BR to CEEE in 1957 could fairly be attributed more to failures of organization and planning than to poor engineering.1/


Eletrobras is the autonomous agency established by the Federal Government in 1961 to carry out power studies, to finance and construct electric power projects and to operate electric power plant and lines. It is generally agreed that one of its goals was the ultimate placing of the industry under the control and ownership of the Federal Government. Under the Branco Government, however, there was no longer an emphasis on socialising the industry, but a trend towards reversion to private control. The main functions of Eletrobras became:

a) a holding company owning the major interest in, and controlling, the federal power utilities;

b) the administration and allocation of public funds to the federal power companies including those in the poorer areas of the country.

By the early 1960s it was becoming evident that the growth of the power load in the south-central region would require the addition of large increments of generating capacity. These could not be obtained by expanding the existing small hydro steam and diesel installations. The early pattern of scattered, fragmented and small power companies could no longer serve as a basis for expansion. There was almost no information on which to base expansion plans for the region.

In 1963-64, a study was carried out to examine the electric power load growth in the region and to prepare an inventory of suitable hydropower sites. The pressure for the study came as a consensus between the Brazilian agencies and the World Bank. The study was financed by the UNDP and the Brazilian Government, with the World Bank as Executing Agency. An engineering consulting consortium, CANAMBRA, supervised the work and published the report.

Following the publication of CANAMBRA's report in 1966, a second, similar study by CANAMBRA was started in South Brazil, the results of which were published in 1969. The findings of these two studies have provided the basis for both short-term planning, and long-term strategic planning, for the coordinated growth of the power sector in Brazil.

1/ See Annex 4.
In both studies 90 per cent of the work (Annex 2) was performed by Brazilians under the supervision of CANAMBRA, which had been chosen through international competitive bidding. Brazilian engineers outnumbered CANAMBRA engineers by more than two to one. The Brazilian engineers were seconded from, for example, Eletrobras, COPEL, CEEE and CELESC, and took a major part in the study formulation, fieldwork, analysis and report writing.

Today, most hydropower design, engineering and planning is carried out by Brazilian engineers, utilities and consulting firms. Foreign consulting firms are associated with Brazilian firms, and the flow of expertise is two-way. Brazil is one of the world's biggest investors in hydropower, and has the indigenous technical capabilities for supporting its massive investment.

5. The Supply of Engineers

In 1966 there were 40,400 registered engineers and architects in Brazil. Of these 20% were electrical engineers and 52% civil engineers. The distribution of engineers by age indicates that there has been a steady supply, particularly in electrical engineering, since at least 1940. (By comparison, the supply of mechanical engineers has been growing much more rapidly, but from a much smaller base.) These hydropower engineers are generally held in high regard by their peers in other countries.

6. World Bank Involvement

From 1948 to 1958 the Bank lent $155m. for the development of the Brazilian electric power sector. Of this $109m. was to Brazilian Traction, the remaining $46m. to CHESF, CEMIG and USELPA. A loan of $25m. to CEEE (64BR) made in 1952 for development on the Rio Grande do Sul was canceled in 1957 by the Bank for basic organizational and administrative defects.2/

These projects were all competently executed, with the exception of the Rio Grande do Sul project. The evaluation of projects by the Bank and its consultants seems to have been that the level of competence of Brazilian expertise and personnel was quite adequate. Foreign consultants were retained in some projects, and some research was done overseas.3/ The Bank frequently became involved in the projects after these arrangements were already in existence. The use of foreign consultants should not be attributed to the Bank.

1/ Source: Engineering Manpower & Development in Brazil 1966-1970
R.L. Cummings, University of Wisconsin
2/ See Annex 4.
3/ For example, turbine research at the University of Toulouse (25BR).
The underlying causes of the Rio Grande do Sul cancellation seem to have been atypical of the general standards of project execution within Brazil at that time. The poor management, financial planning and engineering appear to be an isolated incident not generally found within other projects during this period. However, management expertise in the public sector did tend to be less than adequate during this period. There were some notable exceptions in public utilities, such as CEMIG.

Generally, it may be inferred that the technical development of hydropower expertise in Brazil occurred independently of the Bank's lending and that technical development would have occurred had there been no Bank loans. Advanced technology has been used on a massive scale. The Brazilians have drawn on outside expertise where necessary. For example, by mutual agreement Brazilian engineers studied Extra High Voltage power transmission line technology in Canada, an acknowledged leader in that area. However, the degree of expertise in hydropower in Brazil is probably as great as any country could expect to economically support.

The Bank has contributed, however, to the encouragement and use of sector planning since 1960. It played an active role in encouraging the power surveys of South and South-Central Brazil. As Executing Agent for the UNDP, it chose CANAMBRA to supervise the surveys and produce a development program which has since been called one of the finest of its type. It has fostered institutional developments in the management of electric power supply. It has consistently supported Eletrobras as a vehicle for improving sector planning and for coordinating power generation and transmission. The Bank has continued its encouragement of sector planning in Brazil by including in its recent loan stipulations, in either the Guarantee Agreement\(^1\)/ or Loan Agreement\(^2\), that current and future plans of the Borrower should be in accordance with the Power Survey recommendations.

Recently, the Bank has been encouraging the installation of power supply to low-income areas in the North-East Region. A team has just returned from Brazil after appraising what would be the first Brazil Power Loan to include low-income areas. The loan would support investment to support regular expansion on condition that there was additional investment in low income areas. The amount of money to be lent for the low-income area would be insignificant in the overall lending program to hydropower. However, the support lent by the Bank to this scheme should have a catalytic effect in strengthening Brazilian efforts to develop low income power supply.

\(^1\)/ 728BR. Salto Osorio Hydroelectric Project, April 5, 1971

\(^2\)/ 923BR. Itumbiara Hydroelectric Project, August 1, 1973
7. Conclusions

a) When the Bank was first involved in hydroelectric project lending to Brazil in 1948, there was already existing a cadre of good engineers with expertise in hydropower engineering.

This expertise developed largely as a result of the major private power companies training engineers for their own, considerable, needs in the period 1922 to 1945.

b) There was no major transfer of technology or expertise to Brazil produced by the Bank's lending program from 1945 to 1960.

c) The Bank has played an important role in the production and implementation of a sector planning program. Power development is now taking place in an orderly and strategically sound way.

d) The Bank has taken an active role in encouraging the development of power supply to low-income areas.
   J. Tendler 
   (Doctoral Dissertation)  
2. (Aja) Billings and Water Power in Brazil.  
   Adolph J. Ackerman  
   A.J. Ackerman & the American Society of Civil Engineers. 1953  
   R. L. Cummings  
   University of Wisconsin, Milwaukee Centre for Latin American Studies. Jan., 1971  
4. Power Study of South Central Brazil.  
   Canambra Engineering Consultants Ltd. 
   Nassau, Bahamas. Dec., 1966  
5. Power Study of South Brazil.  
   Canambra Engineering Consultants Ltd. 
   Nassau, Bahamas. Nov., 1969  
   IBRD - Western Hemisphere Department. May 1965  
7. IBRD Loan Appraisals.  
   i) R200 Dec. 27, 1948 (11aBR)  
      Brazilian Traction, Light & Power Co.  
   ii) R330 May 25, 1950 (25BR)  
        Cia Hidro Eletrica do Sao Francisco (CHESF)  
   iii) R408 Jan. 12, 1951  
        Brazilian Traction, Light & Power Co.  
   iv) R611 June 25, 1952 (64BR)  
       Rio Grande do Sul Electrification Program  
       Comissao Estadual Energia Eletrica (CEEEE)  
   v) R700 July 9, 1953 (76BR)  
       Itutinga Hydroelectric Power Project  
       CEMIG.  
   vi) R753 Dec. 10, 1953 (93BR)  
        Salto Grande Hydroelectric Power Project  
        USINAS
vii)  R770  Feb. 11, 1954  
Piratinga Thermal Plant.  
Brazilian Traction Light & Power

Juruminim Hydroelectric Project.  
USELPA

ix)  R58-98  Sept. 9, 1958  
Furnas Hydroelectric Project.  
Central Eletrica de Furnas. S.A.

x)  R58-93  Sept. 3, 1958  
Power Projects in Rio de Janeiro and Sao Paulo.  
Brazil Traction, Light & Power.

8. Contract for consulting engineering services between  
Companhia Paranaense de Energia Eletrica and Canambra  
Engineering Consultants Ltd.  
June 28, 1968       BRA 17

9. Power Development Program for the Southern Region. Plan  
of Operation.  
August 7, 1967       BRA 17

10. April 5, 1971  728BR  
Salto Osorio Hydroelectric Project.  
Guarantee Agreement (See Para. 3.03)

11. August 1, 1973  923BR  
Itumbiara Hydroelectric Project  
Loan Agreement (See Para. 5.05)
Power Study of South Brazil (1966-69)

Manpower Usage

- Total Usage 165 man years
- Brazilian Participation 90%
- Maximum number of people employed (technical and non-technical) 87
- Overall ratio (man months) Brazilian/Canambra 7.7 to 1
  (NB for S. Central Study 9.1 to 1)
- Engineer ratio (man months) Brazilian/Canambra 2.3 to 1
  (NB for S. Central Study 2.8 to 1)

Source: Power Study of South Brazil - Comprehensive Report
Canambra Engineering Consultants Ltd. Sept. 1969
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ANNEX 3

- CANAMBRA - Canambra Engineering Consultants Ltd., Canadian, American and British engineering consortium created to implement the UNDP financed power surveys in Brazil.

- CEEE - Comissao Estadual Energia Eletrica

- CELES - Centrais Eletricas de Santa Catarina S.A.

- CEMIG - Centrais Eletricas de Minas Gerais S.A.

- CHESF - Cia Hidro Eletrica do Sao Francisco

- COPEL - Companhia Paranaense de Energia Eletrica S.A.

- ELETROBRAS - Centrais Eletricas Brasileiras S.A.

- USELPA - Usinas Eletricas do Paranapanema

- USINAS - Usinas Eletricas do Paranapanema S.A.
Cancellation of loan 64BR

1. Loan 64BR to CEEE for the Rio Grande do Sul Electrification Project was suspended because CEEE had failed to carry the project "... with due diligence and efficiency and in conformity with sound engineering and financial practices".1/

2. The Review Mission's findings on the Project position mentioned:
   i) over-centralization of authority and removal of incentives for initiative;
   ii) lack of systematic work planning;
   iii) inadequate financial and accounting methods;
   iv) lack of inter-agency cooperation;
   v) inadequacy of tariff policy.

3. The Mission felt that the basic deficiencies were largely attributable to administrative and organisational defects.2/

1/ Letter to the Director-General, CEEE, from Eugene R. Black, April 20, 1955.

2/ "Appraisal of the present state of execution of the Electrification Program of the State of Rio Grande do Sul in Brazil." WH-43a