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Energy Problems in Latin America

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Latin America is a large subcontinent, including 33 countries with a total area of 20.4 million square kilometers and a population of 350 million (*1*). Except for its southern tip, it has tropical and subtropical climates with no severe winters. Because of the nature of the Spanish and Portuguese colonization of Latin America, local industrial development was discouraged; exportation of primary products and importation of almost all finished products was the rule rather than the exception. Thus most of the countries evolved with a markedly dual character, best characterized as islands of prosperity in a sea of poverty.

Summary. Present energy consumption patterns, known reserves of conventional energy sources (oil, gas, coal, and hydroelectricity), and the impact of the oil crisis on the oil-importing countries of Latin America are discussed. New approaches to energy use, including improvements on end-use efficiency, fuel substitutions, nonconventional energy sources, and changes in consumption patterns, are important. Of particular significance are the alcohol program in Brazil and the possibilities for increased use of hydroelectricity. Investments needed to sustain a reasonable increase in production from conventional energy sources up to 1990 are presented.

A small part of the population in Latin America—the landowners, industrialists, and businessmen dealing with exports and imports (plus the bureaucracy and the army)—constitutes an upper middle class with access to automobiles, modern domestic appliances, and education; this elite represents typically 10 to 20 percent of the population and completely dominates political life. Around them (and around the better districts in the cities where they live) one finds a large population of workers and the lower middle class; the present strong urbanization trend in Latin America feeds this belt of poverty around most cities.

Taken together, these groups represent the "modern" sector of the economy, which uses mainly commercial energy sources such as oil, gas, coal, and hydropower. The rural areas are poor and stagnant; the population of these areas constitutes the "traditional" sector of the economy, which uses, very inefficiently, noncommercial energy sources such as firewood, charcoal, and agricultural residues.

Except for Venezuela, Mexico, Ecuador, and Trinidad and Tobago, the Latin American countries are oil importers, and their modern sector was therefore severely affected by the oil crisis. Overdependence on the use of imported oil (a consequence of extravagant consumption patterns in many cases) and inefficient use of locally available noncommercial energy sources are the basic energy problems of oil-importing Latin American countries.

Importance of Energy Problems in Latin America

Energy is only one dimension of the economic problems of Latin America but is rapidly becoming a crucial one, since the modern sector of the economy is extremely dependent on oil (*2*). This is illustrated by Table 1, which shows commercial energy consumption in 1980.

Petroleum and natural gas together represent 80.9 percent of total commercial energy consumption in Latin America (biomass energy excluded) and only 61.5 percent in the rest of the world. In contrast, coal represents only 4.9 percent of consumption compared to 30.4 percent in the rest of the world. The reasons for this are the scarcity of coal in the subcontinent and the fact that Latin American countries are latecomers to industrialization; therefore the industries introduced in the area by foreign companies were not designed to depend on locally available energy resources but rather on the resource used in their countries of origin, namely oil. The balance of payments of most of the Latin American countries, with the exception of the oil-exporting countries, was therefore tremendously affected by the oil crisis of the past decade. Figure 1 shows the share of total exports represented by petroleum imports in Argentina (a modest petroleum importer) and Nicaragua and Brazil (heavy petroleum importers). As shown by the curve labeled "average Latin American petroleum importers," petroleum imports rose from less than 10 percent in 1973 to almost 35 percent in 1980; in Brazil they reached 52 percent.

This has led many countries to the brink of bankruptcy and threatened the consumption patterns of the elites. The basic reason for such problems is the clear mismatch between the type of energy consumed in the commercial sector and the resources available in each country.

The end-use structure of the energy used in Latin America (*3*) is shown in Table 2. Industry and transportation are very heavily dependent on oil and account for 34.0 and 32.1 percent of total energy consumption, respectively. This is similar to the pattern in industrialized countries.

The mismatch pointed out above is due not only to the industrial structure

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but also to the transportation system, which evolved in such a way that it is based mainly on the use of private automobiles and buses in the cities and highway transportation of freight and passengers elsewhere.

The traditional sector in the rural areas and some slums uses noncommercial energy sources such as fuelwood, charcoal, and bagasse and other agriculture residues (biomass in general). The percentage of total energy consumption represented by bagasse is 73 in Haiti, 69 in El Salvador, 67 in Honduras, 63 in Guatemala, 57 in Nicaragua, 40 in Costa Rica, 38 in both Panama and the Dominican Republic, 33 in Peru, 27 in Uruguay, 25 in Colombia, 23 in Brazil, and 19 in Mexico. Approximately 22 percent of total primary energy consumption in Latin America in 1980 was from noncommercial sources (*3*) (Table 2).

In addressing energy problems in Latin America one cannot, therefore, consider only the supply of energy, although this is an important question in many of the countries. One must also consider the efficiency of present energy use (commercial and noncommercial) and then go a little further and analyze the structure of energy use in an effort to identify ways to change it; in other words, one must also study the demand side of the energy problems.

Table 1. Structure of primary commercial energy consumption in Latin America and the rest of the world in 1980 [from (*2*)]. Noncommercial energy sources are not included.

Energy type	Latin America		Rest of the world	
	$\times 10^6$ TEP	Percent	$\times 10^6$ TEP	Percent
Petroleum	222.8	65.3	2778.7	42.4
Natural gas	53.0	15.6	1253.1	19.1
Coal	16.6	4.9	1989.9	30.4
Hydroelectricity	47.9	14.0	365.8	5.6
Nuclear	0.8	0.2	164.0	2.5
Total	341.1	100.0	6551.5	100.0

Table 2. Energy consumption structure by sector in Latin America in 1980 [from (*3*)]. Values are percentages.

Sector	Energy consumption by sector	Coal	Biomass	Oil and gas	Other fuels	Electricity
Residential, commercial, and public	28.6	0.21	57.24	28.15		14.40
Transportation	32.1	0.09		99.73		0.18
Agriculture	3.8		36.88	56.23		6.89
Industry	34.0	9.18	13.00	58.18	5.01	14.63
Other	1.5		4.79	90.07	0.35	4.79
Total	100.0					

Table 3. Conventional energy reserves in Latin America ($\times 10^6$ TEP).

Country	Oil	Natural gas	Coal	Hydroelectricity		Uranium	Shale oil	Heavy oil
				MW	GWh			
Argentina	362	518	2,359	493	191,000	74		
Bahamas								
Barbados	11							
Bolivia	22	93		232	90,000	1		
Brazil	167	31	8,129	3,083	1,194,900	284	84	
Chile	55		2,984	229	88,600	10		
Colombia	97	112	5,778	774	300,000	102		
Costa Rica				98	37,898			
Dominican Republic				18	7,000			
Ecuador	151	31	98	388	150,400			
El Salvador				12	4,500			
Guatemala	2			15	5,880			
Guyana				186	35,000			
Haiti				10	3,800			
Honduras				6	2,400			
Jamaica				6	2,400			
Mexico	3,900	1,480	2,108	444	99,360	21		
Nicaragua				46	18,000			
Panama				31	12,000			
Paraguay				77	30,000			
Peru	90	29	573	281	109,154			
Trinidad and Tobago	96	152						
Uruguay				25	9,496			
Venezuela	2,448	1,065	5,394	784	304,000			20,000
Total	7,401	3,511	27,423	7,237	2,695,788	492	84	20,000

Energy Resources in Latin America

Looking first at the supply side, one can inquire what the energy resources of the Latin American countries are and where they are located.

Conventional resources. Table 3 shows recent estimates of the energy reserves of Latin America (*2, 4*). Oil and natural gas reserves are highly concentrated in a few countries, with Mexico and Venezuela accounting for almost 80 percent of the total. The total oil and natural gas reserves correspond to 10.5 and 6.0 percent of the world reserves, respectively.

Coal reserves are estimated at $27{,}423 \times 10^6$ tons equivalent of petroleum (TEP) and correspond to a modest 1.7 percent of the world's known reserves. Brazil, Colombia, Chile, Argentina, Mexico, and Venezuela have significant amounts of coal, but in all of these countries except Colombia the coal is of low quality and impurities are extremely high, limiting its use to thermoelectric generation. It is therefore not surprising that coal has not been used significantly in Latin America.

Hydroelectricity is one of the largest energy resources of the area (2,697,788 GWh) and represents roughly 20 percent of the world's resources. Only 7.6 percent of the total estimated resources are being used today, mainly in Brazil, Mexico, Venezuela, and Argentina. Estimated reserves include, in addition to operating stations, stations that are under construction, planned, or technically usable under conditions that are considered economic.

Frequent mention is made in the literature of the "theoretical hydroelectric potential," which is the total potential of a stream if all the energy were developed with 100 percent efficiency (*5*). This number is generally estimated from elevations, precipitation, and runoff, and can be considered only as a rough approximation. The 1976 World Energy Conference (WEC) survey (*5*) value for this potential is derived from information developed over the years by the U.S. Geological Survey, which has been periodically improving and updating a worldwide inventory of hydraulic resources prepared for the Versailles Peace Conference in 1919. The revised number quoted at the World Energy Conference of 1980 in Munich is 5,670,000 GWh (*6*).

The extremely low rate of utilization of hydroelectric resources in Latin America (as well as in Africa and Asia) is striking; hydroelectric power seems to be the "forgotten resource" in the less developed parts of the world, in part because of the high initial investments required to develop it.

The large difference—more than a factor of 2—between the estimated resources and the theoretical potential reflects the fact that surveys usually disregard resources corresponding to less than 20 MW of power and water drops smaller than 15 m (*7*). There are other factors besides neglect of minihydro resources that account for the difference between the theoretical and estimated amounts. According to the WEC survey (*5*), certain river reaches, mainly those near estuaries, cannot be used for power generation for technical reasons, which limits the technical potential even for large-scale hydroelectric generation; some large-scale projects that would be technically feasible are not economically attractive. In addition, some large-scale projects might not be developed for environmental reasons.

Nonconventional energy resources. These resources include solar, wind, and geothermal energy and agricultural and urban residues (*8*).

1) Solar energy: Latin America is mainly within the tropics and therefore receives large amounts of solar radiation; the intensity of light (incident normally in a plane inclined according to the latitude) varies from a minimum of 8 kcal/cm^2 per month in Patagonia to a maximum of 16 kcal/cm^2 per month in the Amazon Valley, depending on the month of the year and geographic location. Local conditions are, of course, important in defining these numbers with any precision.

2) Wind energy: Most of the coastal areas (Colombia, Venezuela, Brazil, Uruguay, Chile, Peru, Ecuador, and the Caribbean region) have winds capable of producing 10 W of power per square meter; the inland areas have winds of only approximately 3 W/m^2. The southern part of Chile and Argentina, however, have favorable winds in the range of 50 to 200 W/m^2. The wind resources of Latin America are poor by global standards; in the central parts of the United States, for example, winds with an average power density of 440 W/m^2 are quite common.

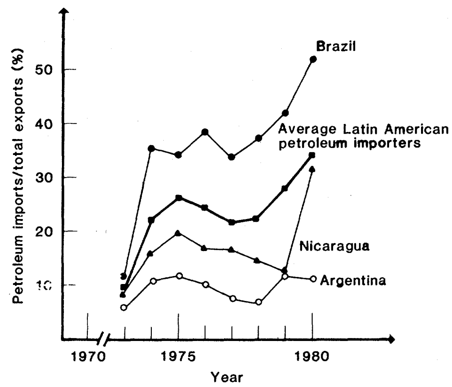

Fig. 1. Share of total exports represented by petroleum imports.

3) Geothermal: This resource is abundant in Mexico, Chile, and El Salvador, where it has been used since the 1970's. All of the Andean region has good prospects for localized use of geothermal power. It has been estimated that 8000 MW of power could be produced in Latin America in identified geothermal resources. By comparison, the present installed hydroelectric capacity in Latin America is approximately 48 MW.

4) Agricultural and urban residues: Estimates of such resources—including fuelwood, charcoal, and forest residues as well as agricultural, animal, agroindustrial, and urban residues—amounted to 138.6 × 10^6 TEP per year on a sustainable basis in 1975. This was approximately half of all the energy consumed in that year (*8*).

Supply Side of the Energy Problem: The Oil-Deficient Countries

A listing of energy reserves does not tell us much about the possibility of mobilizing them for the benefit of the countries that possess them. For this it is necessary to consider the physical and financial constraints involved in utilizing the resources. A 1981 Inter-American Development Bank (IDB) study of investment and financing requirements for energy in Latin America (*4*) addressed precisely this problem. Using reasonable assumptions based on the extrapolation of past trends, the IDB estimated the growth of energy demand for the different traditional fuels (oil, natural gas, coal, and electricity) for the period 1980 to 1990. It took the position that business will remain pretty much as it has been, that there are physical limits to growth in any sector of the economy, and that it should respond to the existing social and energy consumption structure of the countries involved. The first consequence of such a stand is to put great emphasis on exploration for oil, which, if found even in minor amounts, could satisfy the demands of the rising middle class and keep the status quo in the oil-importing countries.

The results of the low-growth IDB projections for 1990 are given in Table 4. For the period 1980 to 1990 the IDB estimates predict that investments in oil exploration, production refining, and transportation will be approximately $98 billion, with the amount of oil produced expected to rise from the 163.5 million tons produced in 1978 to 280.9 million tons. Each additional ton of oil produced per year thus corresponds to an investment of approximately $980; each ton equivalent of petroleum per year of elec-

Table 4. Energy demand projections and investments for Latin America, 1980 to 1990 (*4*). Demands are given in units of 10^6 TEP and investments in millions of U.S. dollars in 1978.

Energy source	Demand, 1978 (×10^6 TEP)	Growth rate, 1978 to 1990 (%)	Demand, 1990 (×10^6 TEP)	Demand increase, 1980 to 1990 (×10^6 TEP)	Investments, 1980 to 1990 (×10^6 U.S.$)	Additional investment needed in the period 1980 to 1990 (U.S.$/TEP)
Oil	163.5	4.8	280.9	~ 100	98,354	980
Hydropower*	14.8	7.4	39.0	~ 22	117,513	5130
Coal	16.6	5.2	30.6	~ 12.3	8,556	690
Natural gas	40.3	6.3	83.5	~ 38	13,193	350
Total	235.1	5.2	434.1		241,078	

*1 GWh of hydroelectricity was assumed to correspond to 86 TEP, which is its physical caloric content. If one takes the more reasonable value of 1 GWh = 3 × 86 TEP (which corresponds to the replacement value of hydroelectricity by electricity generated from oil), the investment per TEP of hydroelectricity falls to U.S.$1710 per TEP.

tricity corresponds to $5310, of coal to $690, and of gas to $350.

All other energy sources, with the exception of alcohol from sugarcane in Brazil, are considered noncompetitive.

Total investments needed in the period 1980 to 1990 are projected to be $241.1 billion ($24 billion per year), which is beyond the present financial capabilities of the countries themselves and of the international development banks.

Demand Side of the Energy Problem

In contrast to these gloomy prospects, some energy analysts point out the abundance of nonconventional energy sources such as solar radiation in Latin America and on that basis paint a very rosy picture of the future. For example, assuming that the average intensity of solar radiation is 16 kcal/cm^2 per month (*8*), if all the solar energy incident on an area of 1600 km^2 (a 40 by 40 km square) were collected and used with an efficiency of 10 percent by photovoltaic cells, one could generate as much electricity as was produced in 1978. Arguments of this type can also be made for wind and other nonconventional sources. However, such reasoning does not take into account costs, physical limitations, and lack of experience and technology.

Between the two widely different positions outlined above, there are many improvements in end-use energy efficiency, fuel substitutions, and changes in consumption patterns that are economically sound and could help to match locally available resources to needs. Conservation measures include not only "technical fixes" but also the reorganization of systems to use energy more rationally. These considerations apply not only to oil-poor countries but to petroleum exporters as well. A number of examples of what can be done along nonconventional lines are given below.

Conservation in the industrial sector. The industrial sector in Latin America was either copied from abroad or installed in the country by foreign companies. In some countries many industrial goods are produced locally, but the machinery or the design of the products is imported; as a consequence, industrial parks are modern and many of the methods employed in the industrialized countries to conserve energy are also applicable in most of Latin America. Since 1973, many of the large companies have improved the performance of their equipment, and energy savings of 15 percent through retrofitting of industrial equipment are not uncommon. Prices of fuels used in industry have been increased to encourage conservation, except in the petroleum-exporting countries.

Conservation in the traditional sector. Energy in the rural areas is used mainly for cooking and comes from fuelwood, which is very inefficient (*9*). Conservation has taken place in this area not through the improvement of cooking stoves but mainly through the substitution of liquefied petroleum gas (LPG). Bottled gas is the basis of a thriving business in the rural areas in many countries. Slums and poor areas of the cities have also switched to LPG and kerosene. Since surface burners (using gas or kerosene) have typical efficiencies of about 48 percent and fuelwood cooking stoves have efficiencies in the range of 5 to 15 percent, the net energy gain is large (*9*).

Although the shift from fuelwood to LPG saves energy, it increases the dependence on oil; for example, in Brazil LPG represents approximately 6 percent of all the petroleum used in the country. The use of alternative cooking fuels such as biogas, gas produced from wood, and hydrogen produced by electrolysis in hydropower-rich countries should be encouraged.

Electricity is also widely used in the slums of urban areas. A study conducted in the rural and urban areas of São Paulo, Brazil, showed that the total expenditure for primary energy per household in the slums was smaller than in the rural areas for the same income, although it offered many more amenities such as lighting, radio, television, and household appliances (*10*).

Cities offer many more attractions than rural areas (including better access to jobs and to health and social services), and this is the origin of the strong urbanization trends in Latin America, since incentives to remain in the rural areas are almost nonexistent.

Fuel substitution in industy and transportation. In a few countries fuel oil is being replaced by fuelwood and pelletized biomass residues for the production of steam; multifuel boilers have been developed for that purpose with good economic results. In Brazil, where the government compelled industry to move in this direction by rationing the supply of fuel oil, regulatory action rather than price increases led to substitution. Replacement of fuel oil by biomass requires the development of energy plantations; otherwise, indiscriminate deforestation will occur. Energy plantations based on eucalyptus and pine have been successful in Brazil, where yields of 10 tons per hectare per year have been achieved at attractive prices of less than U.S.$1 per gigajoule. In Colombia coal is replacing fuel oil in industry.

Hydroelectricity can replace diesel and fuel oil in some industrial applications where quality control and purity are important, such as in the production of special steels in induction furnaces, where the material to be handled can be kept isolated from impurities. Since hydroelectricity is abundant in a number of Latin American countries, this is a possibility that should be better explored.

Electrified mass transit systems are being introduced in a number of Latin American cities, resulting in decreased traffic congestion and better use of the land. In addition to older systems, there are the São Paulo and Caracas metros as well as new systems of trolleys in Bogotá and other Colombian cities.

The most important substitution program introduced in Latin America so far is the production of ethanol from sugarcane to replace gasoline in Brazil. The price mechanism was used to discourage the use of gasoline-fueled automobiles and trucks and to make feasible the use of ethanol. In 1981 approximately 60,000 barrels of gasoline per day were replaced by ethanol, either used as a pure fuel or mixed with gasoline in amounts up to 20 percent. In 1981 and 1982 approximately 300,000 automobiles running on pure ethanol were introduced in the market each year (*10*).

The feasibility of an ethanol program is tied to technical and economic constraints related to the use of sugarcane as a raw material. This makes the program very country-specific. Efforts to produce ethanol from cellulosic material are under way in Brazil, and it should be possible to evaluate this program by the end of 1983. Cellulosic feedstocks (wood or agricultural wastes) can be produced on marginal lands at higher efficiency and probably lower cost than sugarcane (*10*).

Methanol is another possible fuel for automobiles and trucks and has the advantage that it can be produced from natural gas, coal, and biomass. Another possibility is the use of producer gas from wood or charcoal. Energy efficiency improvements in transportation can considerably stretch the potential of biomass fuels; all-aluminum cars (mainly in hydro-rich countries) and superefficient cars of novel design are important options for some Latin American countries.

The "rehabilitation" of biomass (*11*) for use as a modern fuel, in pelletized form or in the form of ethanol or methanol, producer gas, or biogas, can help to stop the historical trend of a diminishing role for biomass in most Latin American countries.

Reorganization and rationalization of energy uses. The strong urbanization trends in Latin America have led to a substantial number of large cities doubling in size every 12 years (6 percent growth per year). This is a very high rate of growth and is equivalent to adding to a city such as São Paulo (12 million people) another one such as Brasilia (700,000 people) every year. Similar growth is taking place in Mexico City and Caracas.

This growth creates great problems but also offers possibilities for innovation and for use of the most advanced and efficient technologies. The role of retrofitting in improving energy efficiency in industrialized countries should be replaced by new and improved design in the developing countries. New steel mills in Latin America, for example, should not be copies of the antiquated mills of the United States but should be based on modern, energy-saving technologies. The same applies to transportation systems and in a way is taking place when high-compression engines operating on ethanol are used, since they are more efficient than conventional low-compression engines running on gasoline. Other improvements can result from improved aerodynamics, tires with less rolling resistance, direct-injection diesel or multifuel engines, and automobiles with lighter bodies.

Even the design of cities can be improved, and regulations can have a great impact without the need for heavy investments. An outstanding example is the city of Curitiba in southern Brazil, where urban planning coupled with a modern transportation system—based on exclusive lanes for buses along radial corridors from the center of the city—has reoriented growth in such a way that the city remains pleasant even though its population has surpassed 1.4 million and will probably reach 3 million in the next 10 years.

Prospects

Although there are many ways to relieve the energy problems in Latin America, one finds in many of the countries a maze of conflicting entrenched interests and institutional constraints that leads to complete immobility in the area of energy policy, and even to some absurdities. In Colombia, for example, trucks and buses run on gasoline rather than diesel oil. Other countries are moving quickly in a number of innovative directions, while still others lack the organization to collect taxes in an efficient way.

Since the state apparatus in most countries is firmly in control of the elites, it depends basically on their wisdom and leadership to make changes and introduce new policies. The degree of enlightenment in the subcontinent varies widely from country to country, which makes all the more valuable the advice, loans, and actions of international banks and organizations such as the Latin American Organization for Energy (OLADE) and the Organization of American States (OAS).

OLADE is a newly formed regional organization of Latin American states with headquarters in Quito, Ecuador. So far it has produced energy balances for most of the countries in the area and offered technical advice on specialized topics such as geothermal energy and minihydroelectric stations. It also promotes frequent meetings of the ministers of energy of the several countries, which has had important political results and has led to increased trade.

OAS is the oldest inter-American political body; all the American countries except Canada and Cuba are members. Its headquarters are in Washington, D.C. For many years OAS has promoted scientific and cultural programs between the participating countries. Its Department of Regional Development has assisted numerous governments in natural resource development projects. As part of these activities, the department began in 1980 to conduct specific studies related to energy development. Its principal efforts so far have been concentrated on rural energy projects in Central America and the Caribbean and on energy conservation in the transportation sector in Colombia and other countries. OAS has proposed that energy atlases be prepared for a number of Latin American countries to enable them to address their energy problems with emphasis on regional characteristics and the matching of resources to needs.

A number of European countries as well as the United States have bilateral aid programs to several countries in the area, mainly in Central America and the Caribbean. Most of these programs use a supply-side approach to promote nonconventional energy sources, concentrating on the commercialization and use of sophisticated equipment such as modern windmills and air-conditioning systems.

A recent improvement in energy policy took place in Mexico, where gasoline and other derivatives had been sold to consumers at less than 50 percent of their international prices. Financial insolvency at the end of 1982 led the government to readjust prices in order to discourage extravagant use and waste. Prices are still being maintained at extremely low levels in Venezuela, one of few countries where gasoline-guzzling automobiles are still found in large numbers.

Conclusions

Latin America includes many countries with similar structural problems, but because of the diversity of the countries' natural resources the problems have different solutions. It might be useful to remember that one can categorize planners (particularly energy planners) in two opposite schools of thought: "geneticists" and "teleologists" (*12*). The geneticists argue that planning goals are constrained by and must be based on "objective tendencies" that are inherent in the economic situation of a country; that is, past trends and tendencies determine a country's future just as our genetic heritage shapes our future. In contrast, the teleologists maintain that the objective one has in mind is decisive in the planning process; one of the goals of planning is to transform the economic situation and inherent tendencies of a country. Directives, and not forecasts, should be the basis of the planning process, which should be regarded as a political activity with options and choices and not merely an economic and technical process.

These two viewpoints are reflected in two forecasts of the energy future of Latin America for 1995 made by the International Institute of Applied Systems Analysis (IIASA) and the Bariloche Foundation.

The IIASA study (*13*) is a hardheaded, market-oriented extrapolation of past tendencies which can in many respects be considered to represent a geneticist approach. In contrast, the Bariloche Foundation study (*8*) stresses the importance of renewables and suggests that this is the direction in which to move; in other words, it represents a teleologist approach.

The two forecasts give values for the total energy consumption in 1995 that differ by less than 15 percent but are quite different in the mix of energy sources that they use. The IIASA projection is for a future in which oil, coal, and nuclear energy are very important and renewables (including hydro) represent only 16.1 percent of the total energy. The

Bariloche Foundation projection assigns 37.9 percent to renewables, with less oil and coal and little nuclear energy.

These strongly contrasting studies indicate that there may be considerable flexibility in developing the energy future of Latin America; it is likely that neither of them has given enough attention to improvements in the end uses of energy. It is clear, however, from the active search for new solutions and innovations that the oil crisis of the 1970's has had an impact. The search for new solutions will certainly lead to an energy future that will be different from the past, perhaps less than wished by many but more than predicted by some.

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RESEARCH ARTICLE

Effects of Cyclosporine Immunosuppression in Insulin-Dependent Diabetes Mellitus of Recent Onset

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Introduction

Type I diabetes mellitus occurs at an annual rate of approximately 15 per 100,000 people with a prevalence of 1 in 300 among those under the age of 20 years in North America. The incidence is increasing each decade with a clear genetic predilection and a strong association with the major histocompatibility complex (*1*). In particular, the disease is associated with DR antigens 3 and 4 of the HLA (histocompatibility) region with greater than 90 percent of patients under the age of 15 years having DR3 or DR4 or both. The etiology of the disease is not known. The possibility that viral infection has an etiological role is suggested by findings in animal models, but the occurrence of diabetes in the human as a direct result of a viral attack on the β cells appears to be a rare clinical event (*2*). That the disease can result from autoimmune processes is also suggested by studies in animals, particularly the BB rat, which serves as a telescoped model of type I diabetes (*3*). This animal develops gross abnormalities of the immune response including a T-cell lymphopenia preceding and accompanying the onset of the disease (*4*). The disease is genetically dominant and linked with the major histocompatibility complex (*5*). Although islet cell antibodies (*6*) have been described in association with diabetes in this rat model, the primary immunologic mechanism appears to be cell mediated. The disease in the BB rat can be prevented by a number of manipulations of the immune system (*7, 8*), including the administration of cyclosporine (Cy) prior to the onset of the disease (*9*). It was found that Cy completely prevented the acute isletitis, which destroys the β cells in 80 percent of untreated BB rats, while sparing the acinar tissue. If Cy was continued, the pancreas remained free of the cellular infiltrate. When Cy was discontinued at 120 days of age, diabetes occurred in less than 25 percent of the animals (*10*).

In the human, the evidence that type I diabetes is an autoimmune disorder is based largely on the histological appearance of the pancreas (*11*), the demonstration of cell-mediated immunity against islet cells (*12*), and an association of islet cell antibodies with the disease (*13*). Its association with a number of diseases where autoimmunity has been implicated such as Grave's disease, pernicious anemia, Hashimoto's thyroiditis, myasthenia gravis, and Addison's disease adds to the impression that it is immunologically mediated. The conviction that type I diabetes is mediated by immune mechanisms has already prompted a number of attempts to induce remissions in the human by the use of immunosuppressive agents early in the course, with inconclusive results to date (*14–17*).

The diagnosis of type I diabetes carries a sinister prognosis with an overall mortality of 60 percent four decades after the initial diagnosis is made. Uremia is the cause of death in over 30 percent of patients. It is expected that within this time, 16 percent will be blind, 21 percent will have a myocardial infarction, 12 percent will have gangrene or have undergone amputation, and 10 percent will have suffered a stroke (*18*). In recent reports it was estimated that the relative mortality in comparison to nondiabetics (*19*) is greater than ten times at any age, and that as many as 1.4 percent of patients with juvenile onset insulin-depen-

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