

1983 UPDATE PUERTO RICO
ENERGY ALTERNATIVES

By

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May 1983



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UNIVERSITY OF PUERTO RICO -- U.S. DEPARTMENT OF ENERGY

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CONTENTS

PART I - Results and Conclusions

In this part we show some figures and tables which summarize our study. Then a few objective conclusions are drawn from the results of this analysis.

PART II - Questions and Answers Regarding Puerto Rico Energy Alternatives

In this section some questions and answers relevant to the present and future economic status of Puerto Rico are presented.

APPENDIX A - Economic Equations

In the sections C1, C2 and C3 (C stands for Capital) of this Appendix we describe the main factors which appear in the economic equations which calculate the total \$/KWH of any of the energy alternatives.

In sections F1 and F2 (F stands for fuel) we calculate the economic equations for the fuel cost in \$/KWH levelizing throughout the life of the plant.

In sections OM1 and OM2 (OM stands for operation and maintenance) we calculate the levelized cost throughout the life of the plant.

The total Electricity Cost levelized throughout the life of the plant is then

$$E.C = (C_L + F_L + O\&M_L)$$

where the suscript L stands for levelized.

APPENDIX B - New Data Source

In this appendix we discuss the new assumptions, based on some references given at the end, which served to elaborate this work.

PART I

RESULTS AND CONCLUSIONS

Our conclusions is that Puerto Rico's energy situation is primarily due to nearly complete dependence on oil. Steps should be taken to reduce this dependence in the future.

In addition to the current measures being taken to reduce consumption, the most promising area in reducing oil consumption is electrical production. A program to reduce oil consumption by 50% for electrical generation within the next 15 years could be considered as an appropriate objective. The most promising alternative for fuels are nuclear or coal with the optimum solution utilizing both. In addition, a promising source of energy in smaller quantities is available from bagasse (a by-product from our sugar cane industry). This energy source appears economically competitive with coal. A commercial enterprise for producing biomass (energy cane and other CSEER developed tropical grasses) could compete favorably in the local energy market. The main restriction to its broader use, will be the use of land for more higher value production.

These conclusions are supported by our calculations which resulted in figure 1 and table 1. The curves shown in figure 1 were determined using the following consistent assumption. All 1983 costs: Capital, Fuel and Operation and Maintenance Costs are carried over to 1985 and then, at that year, a 7% inflation rate and 10% interest rate are allowed.

As we see the most economic solution is Nuclear with a total levelized cost for 1990 (see figure 1 and table 1) of 0.07/KWH. Then Coal is next with 0.127/KWH. Then biomass very closely to coal with \$0.131/KWH. The comparative oil cost is \$0.168/KWH. Wind and photovoltaic alternatives generate electricity at much higher values, at \$0.210/KWH and \$0.488/KKW respectively.^a

^aCalculated from data reported in Reference 10 and 8 respectively.

PART - II

QUESTIONS & ANSWERS REGARDING
PUERTO RICO ENERGY ALTERNATIVES

530

Figure 1.

Levelized Cost For the Different Alternatives

All cost are affected by 7% inflation rate and 10% interest after 1985.

a) Calculated from Data reported in Ref. 10

b) Calculated from new Data reported in Ref 8

450

410

390

370

350

330

310

290

270

250

230

210

190

170

150

130

110

90

50

PHO₁ (b)

W₁ (a)

O₁

B₁

C₁

N₁

- N₁ = Nuclear
- C₁ = Coal
- B₁ = Biomass
- O₁ = Oil
- W₁ = Wind
- PHO = Photovoltaic.

\$/kWh (1985)

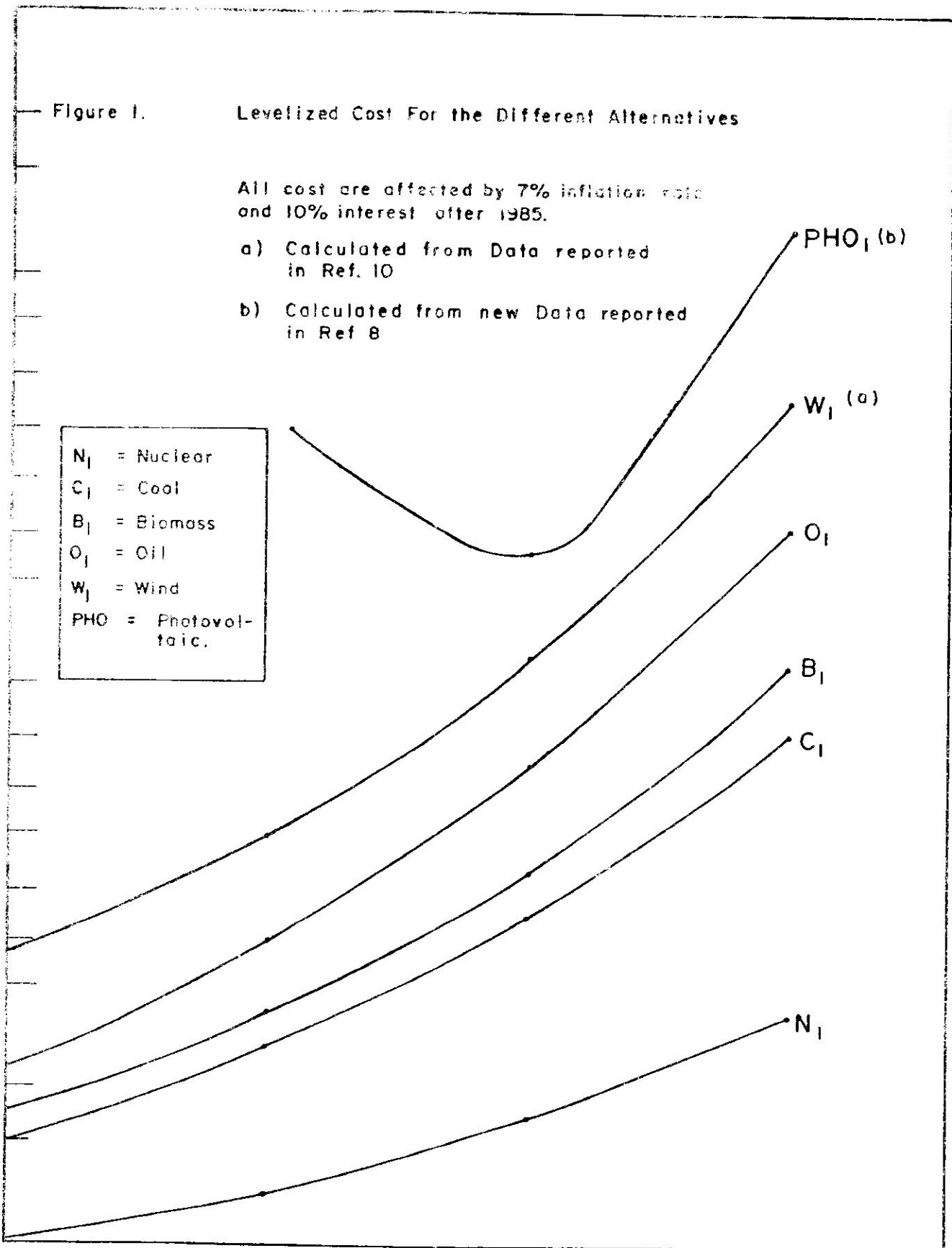
1985

1990

1995

2000

Year 5



1. What is the background of Puerto Rico's economic condition?

The economy of Puerto Rico is a section of the USA economy cycling as follows. In the period before 1973 the Puerto Rican economy was dynamic, growing faster than the United States economy as a whole, propelled by lower oil and labor costs as well as by US government support.

After 1973, oil price increases reversed Puerto Rico's oil cost advantage.

The economy has grown afterwards at a much slower rate.

ECONOMIC GROWTH RATES

	1960-73 %/year	1973-80 %/year	Growth Comparison %
Puerto Rico	7.4	3.1	40
USA	3.1	2.5	80

The growth in employment was also reduced.

EMPLOYMENT GROWTH RATES

	1963-70 %/year	1973-80 %/year	Growth Comparison %
Puerto Rico	5.1	1.1	22
USA	2.2	1.5	68

Puerto Rico's economy continues to be depressed as of March 1983.

2. Is the high cost of oil the only factor affecting Puerto Rico's development?

No, it is only one of many. However, it is an area where governmental action will have very direct and positive results. Energy is particularly important to Puerto Rico because the Commonwealth is a

relative high user of energy as can be seen by the table below reflecting World Bank information.

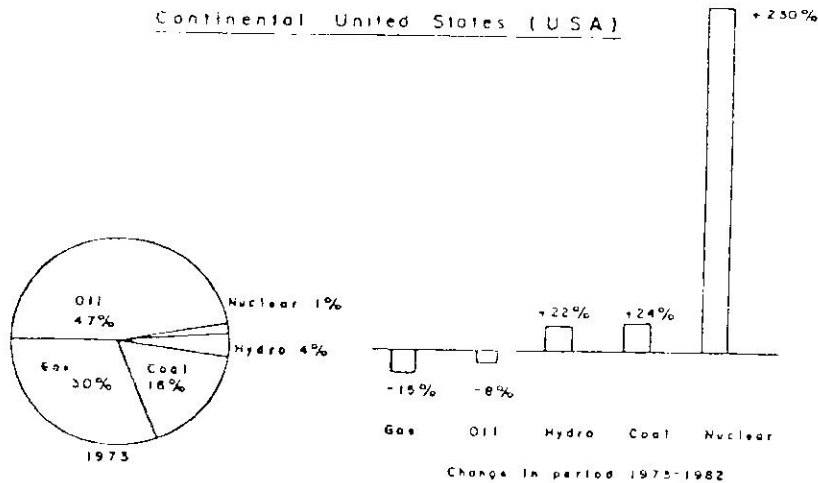
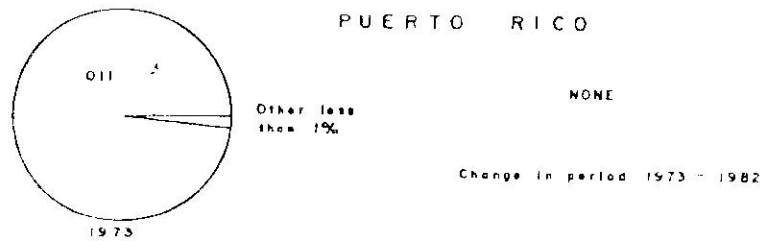
Use of Primary Energy
(Barrels/Capita-Year)

Puerto Rico	20
High Income Countries	19
Med Income Countries	5
Low Income Countries	2

3. Why is the Puerto Rican's economy so susceptible to changes in oil prices?

Puerto Rico is not only a high energy user, but it depends almost exclusively on oil. In contrast, the US not only enjoys a certain degree of energy source diversification, but it is also moving toward the use of lower cost energy sources.

ENERGY SOURCES



4. How can Puerto Rico's dependence on oil be reduced?

Puerto Rico's use of oil is mainly for

Transportation	25%
Electric Production	45%
Chemical Industry	20%
Feedstock	10%

Oil usage reductions are achievable primarily by conservation in the field of transportation, and by a combination of methods in the chemical industry. These changes are in the process of implementation in response to the high cost of oil and its by-products.

In the case of electric production, conservation also results from high prices. However a better solution is the reduction in the cost of generating electricity by substitution of oil by lower cost energy sources. This can only be done by the Puerto Rican Government.

5. Is the price of electricity higher in Puerto Rico than in USA?

Yes, in 1981 the average prices of electricity were

Puerto Rico	9.82cents/KWH
USA (Average)	5.00cents/KWH
South Carolina	4.13cents/KWH

The difference is also getting larger as can be seen from the chart below.

AVERAGE PRICE OF ELECTRICITY

	1973 cent/KWH	1981		Rate of Change (Constant \$)	
		Current Dollars cent/KWH	Constant Dollars cent/KWH		%
Puerto Rico	2.27	9.82	5.35		135
USA	1.86	5.00	2.72		46

6. Have those high prices deterred electrification and therefore reduced the productivity of the economy?

Yes - The price of electricity while low in the short term increases significantly with time. The consequences are reflected in the table below.

	1960-1973	1973-1980	Change in Growth Rate
	%/year	%/year	%
Puerto Rico	13.9	1.9	7.3:1
USA	6.8	2.6	2.6:1

7. What is the reason for the high cost of electricity in Puerto Rico?

The exclusive dependence on oil. It can be seen by the tables below that when comparing prices in different states, the price of electricity declines where less oil is used for the electrical production.

As a consequence, the electrical utility industry in the US has shifted toward the lower cost fuels. In the period 1973 - 1982 the use of

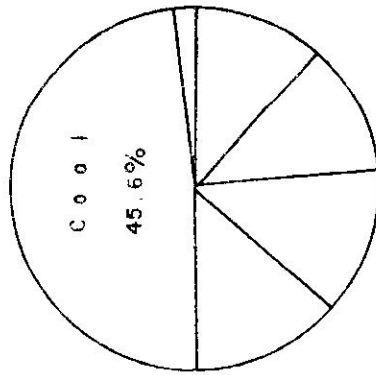
Oil	decreases	33%
Gas	increased	2%
Coal	increased	42%
Nuclear	increased	220%

The World Bank advised that the developing countries plan to reduce the use of oil for electricity generation from 24% in 1968 to 6% in 1995.



TRENDS IN ELECTRICITY PRODUCTION

1973



U. S.

Oil 16.9%

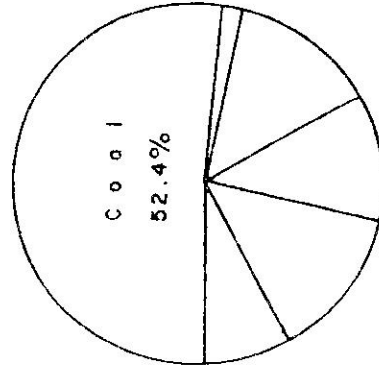
Gas 18.3%

Hydro 14.6%

Nuclear 4.5%

Other 0.1%

1981



Oil 9.1%

Gas 15.1%

Hydro 11.9%

Coal 52.4%

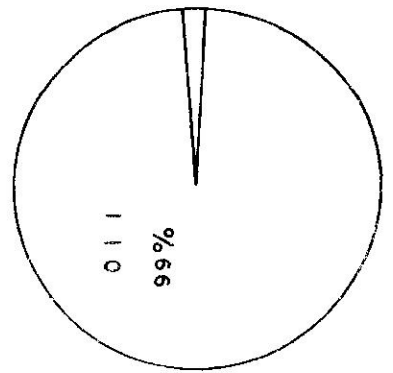
Nuclear 11.9%

Other 0.1%

2,295

Billion of Kilowatt - Hours

1973



Hydro 1%

Hydro 1%

Oil 99%

PUERTO RICO

1,861

Billions of Kilowatt - Hours

8. Will the recent reduction in oil prices reduce the magnitude of the problem?

Oil prices today are only slightly lower than the 1981 prices used as reference.

Further oil price reductions may occur but they are expected to be short lived. The position of the oil producer countries to raise prices will improve when the demand increases as a consequence of the leveling in oil prices and the end of the recession.

The forecast in the long run continues to be for oil prices to increase faster than the general level of inflation.

It should be noted that 70% of the oil exports originate from the Arab world, bringing into question the reliability of supply.

9. What are the alternatives to oil for electric generation in Puerto Rico?

Gas, hydro and geothermal are not in consideration because the island does not have the natural resources. Breeder reactor, nuclear fusion, and sea power are not in consideration because no commercial technology will be available in the next 30 years.

Coal and nuclear are proven sources of possible immediate application, biomass could be used in a limited manner; solar-photovoltaic and wind, while not economical today, could become practical alternatives if their capital cost is significantly reduced by technological development.

10. What are the possible savings from using alternative fuels in Puerto Rico?

For a reasonable set of assumptions the levelized cost of electrical generation for a plant that starts operation in 1990 was calculated to be

Oil	16.9	c/KWH
Biomass	14.1	c/KWH
Coal	12.8	c/KWH
Nuclear	7.1	c/KWH

Biomass (sugar cane or sorghum dried and burned in boilers) could be conceivably competitive with coal.

Wind and solar-photovoltaic are not current solutions. Cost of energy with the same assumptions above are:

Oil	16.9	c/KWH
Wind ^a	21.0	
Photovoltaic ^b	48.8	

The cost of the electricity generated by these sources must be significantly reduced before they become competitive for Puerto Rico conditions. This is not likely before the end of the century.

To set in perspective the savings possible with the use of alternative fuels, if 50% of the current electrical output of 13 billion KWH were produced by coal or nuclear the potential savings would be (in 1981 dollars).

Coal	166 million dollars/year
Nuclear	397 million dollars/year

The cost of electric power shown gives nuclear a very substantial advantage. This is contrary to estimates in the USA, that show much less advantage for nuclear power over coal power.

a) As calculated from data reported in Ref. 10.

b) As calculated from data reported in Ref. 8.

Actual international experience gives a 40% advantage to nuclear over coal. This advantage increases where sophisticated environmental controls are required for coal. Also the cost of coal is higher in Puerto Rico compared with USA because of increased prices for transportation and handling. Finally the US estimates reflects implementation schedules, much longer than necessary.

11. What would be the benefits to Puerto Rico of reducing oil dependence in electrical production to 50%?

More than 1 billion dollars per year.

12. What will be the source of the capital required to carry out the investment required to achieve the above objective?

The financial community will be willing to advance the funds necessary both for capital cost and for interest during construction, if the investment is warranted by the Commonwealth.

As soon as a plant is in operation, the savings in oil imports will permit repayment of the loan, as well as the operating expenses and fuel leaving a large surplus that will permit a reduction in the price of electricity.

13. How will the environment be affected by the different alternatives to the use of oil for electrical generation?

	Land required acres/MW	Oil slicks	Sulphur	Parti- culates	NOX	Coal/ dust	Ash dis- posal	Radiation	Radio- active waste	Noise	Transportation
Oil	1/4	X	X	X	X	X					
Coal	1		X	X	X	X	X				X
Nuclear	2								X		
Biomass	280			X	X	X					X
Wind	280									X	
Photovoltaic	60										X

14. What will happen to the competitiveness of coal generated electricity if the assumptions utilized in the estimates do not materialize?

The estimates of coal power costs are sensitive to:

1. Relative cost of coal vs. oil. The abundance of coal and the consequence of using oil determines that coal prices are driven by those of oil. Furthermore, coal generated electricity will be cheaper even if the coal to oil price ratio increases by 50%.
2. The availability factor of the coal power units. The availability of large units with strict environmental controls has been low, of the order of 60%. It may increase as the technology is better understood. Coal power is competitive with oil even with an availability as low as 50%.
3. The assumed rate of inflation. Because of its higher capital investment, coal power has an edge against inflation and will be penalized if a deflation will occur after plant completion. Coal continues to be competitive with oil even after deflation rates of 300%.

15. What are the environmental effects resultant from the use of coal?

The most significant effects result from the huge mass of material to be transported, handled and disposed. If generation facilities produce half of the current Puerto Rican electricity output, the following flows result:

Coal Transportation	1.5 million tons/year
Ashes to be Buried	150,000 tons/year
Particulates Released to Atmosphere	4,000 tons/year
Sulphur Removed	20,000 tons/year
Sulphur Slurry	100,000 tons/year
Sulphur Oxide Released to Atmosphere	10,000 tons/year
CO ₂ Released to Atmos- phere	4 million tons/year

While most of them result in expenses and nuisance rather than danger, the effects of the release of CO₂ is currently a widespread concern of the scientific community because of its eventual effects on world weather conditions.

16. What will happen to the competitiveness of nuclear generation if the assumptions utilized in the estimates do not materialize?

The estimates of nuclear power competitiveness are sensitive to

1. Future Cost of oil. However to become competitive, the price of oil in constant dollars must go down to \$10 a barrel, the price of coal to \$25/ton.
2. The availability of the nuclear plant. The availability of 600MW nuclear plants has historically been high and should be

even higher (above 75%). In any case, nuclear will retain its economical advantage over oil even if it is utilized at only 25% of its nominal rating, while the advantage over coal still exists for an availability factor of the order of 33%.

3. The initial capital investment assumes the use of a proven design and the execution of the project by a competent team under a streamlined NRC regulatory review. These are necessary conditions for the options to be a practical alternative. However capital costs must be four times greater before it loses its advantage over oil, 2 1/2 times for the case of coal.

17. Which objections have been raised to preclude considerations of nuclear power?

Several objections have been raised:

One of them is that because electric consumption in Puerto Rico is not growing, we do not need new generation power.

Electric consumption has not grown because of the general recession of the economy and as a reaction to the increase in electricity prices. Demand will increase again once the recession ends and as the price of electricity levelizes. Furthermore, new generation facilities with alternative fuels will result in large savings even if the demand does not grow because of the high operating costs of the existing oil burning units.

A second objection raised against nuclear power is that the commercial units currently available are too large to fit the size of the Puerto Rican system.

Nuclear power has been introduced in other electrical systems of similar load demand to Puerto Rico.

The smaller reliable nuclear units available today are rated at 600 MW. They can be competitive with oil even if operating at 200 MW, and with coal at 300 MW. Adequate reserves to permit satisfying the electrical demand during refueling and maintenance of the nuclear unit will be provided by the existing oil facilities (4200 MW).

18. But is not nuclear power risky?

In the world there are about 260 reactors in operation and about 220 in construction. Thus, humanity has lived through about 2000 reactor-years with no fatality resultant from the nuclear portion of the plant.

This contrasts with the numerous accidents and illness that result when using oil for power generations, including transportation of oil, its refinement, equipment failure such as boiler explosions, fires like that of TOCOA, and pollution from the oil leaks and combustions products.

There is a potential risk that an accident in a nuclear power plant will result in the loss of hundreds of lives. However this risk is extremely low, less than one case in 100,000 years.

Nuclear Reactors in the World

<u>COUNTRY</u>	<u>OPERATING</u>	<u>UNDER CONSTRUCTION</u>
Argentina	1	2
Austria	-	1
Belgium	3	4
Brazil	1	2
Bulgaria	3	1
Canada	10	14
Czechoslovakia	3	8
Finland	3	1
France	29	30
Germany (GDR)	5	-
Germany (FR)	10	16
Hungary	-	4
India	4	6
Italy	4	5
Japan	23	12
Korea	1	8
Mexico	-	1
Netherlands	2	-
Pakistan	1	-
Philippines	-	1
Poland	-	2
Rumanie	-	3
South Africa	-	2
Spain	3	11
Sweden	9	3
Switzerland	4	2
Taiwan	3	3
United Kingdom	32	10
United States	74	74
USSR	33	4

19. Does the public have to be protected for thousands of years from the nuclear waste generated by nuclear power?

Most of the waste from a nuclear plant is low level, as that generated in a hospital, and its disposal will follow proven methods already in use in Puerto Rico.

The spent fuel, in contrast, is highly radioactive and must be handled safely. This will be done either through reprocessing outside the island or in the national waste repositories that will result from the application from the high-level waste policy act.

Storage and transportation of spent fuel has not resulted in accidents in the 2000 reactor-years of nuclear operations to date.

The spent fuel generated from a nuclear plant is only a minute fraction of the waste resultant of fossil combustion and therefore the problems resultant from its disposal are simplified.

20. Cost and schedule of nuclear plant construction in the USA has risen out of control during the last decade. How will this be avoided in the case of Puerto Rico?

The increases in cost and schedule of US nuclear construction can be explained by a combination of a period of extraordinary expansion in the nuclear industry in the USA, its fragmented nature, and the nature of regulation in the USA.

There is a recognition in all segments of the industry that it must come back to shorter schedules and lower costs. This can be accomplished if the following elements are available for new plant construction:

- a well studied site
- a proven design with a good level of definition

--- a competent and experienced implementation team

--- review and agreement with the site and design by the owner and by the NRC before start of construction

In the case of Puerto Rico, the Islote site is well studied and proven 600 MW design is available which will meet all current NRC requirements. Only a Probabilistic Risk Analysis remains to be made to permit review by the NRC.

21. What is the feasible schedule for implementing a program that will reduce Puerto Rico dependence on oil?

1983 Decision to proceed

1984 Preparation of a plan with specific proposals for approval and release for implementation.

1985 Start of program implementation

1991-2 Start of operations of first generating facility utilizing alternative fuel

1995 Achieve goal of reducing oil share in electrical power generation to 50%.

22. The effects of the proposed program to reduce dependence on oil will only reduce electricity prices in 1990's. Which are the immediate benefits of the program?

A program as proposed will result in immediate benefits as the result of the implementation process.

Local direct construction expenditures will be in the order of 600 million 1981 dollars and its multiplication factor will result on an economy incentive of 2 to 3 billion dollars of added circulation.

This represents around 25,000 man-years of direct employment and 100,000 man-year of indirect employment during implementation of the project.

These effects will increase with a higher nuclear share in the program, will decrease if the nuclear share is lower.

23. What are the advantages and disadvantages to result from the use of biomass as a source of power?

Primary advantages are:

- fuel is native
- it generates agricultural employment
- at the same time it generates power it may yield some molasses

The disadvantages are:

- extensive land requirement (40,000 acres are required to satisfy about 10% of current power demand). However for small plants like 20MW Plant, the land is available in the sugar cane fields of the government of Puerto Rico.
- high mechanization of operations required to reduce costs reducing employment with reference to other possible uses of the land.
- economies require efficient combination in large size units.

Only small, inefficient units are currently available. Technology must be developed to the commercial operations phase before generation costs can be established.

It is interesting to note that in 1935 Eng. Luis A. Ferré had already made a detailed study of the use of bagasse to generate electricity in Puerto Rico (reference 13).

APPENDIX A
ECONOMIC EQUATIONS

Capital Investment

C1. The initial Capital Investment C can be calculated given

1. CO : Basic cost calculated in dollars per kilowatt corresponding to the base year of investment (BYI) and
2. K : Special adders for a particular site and utility organization
 CO in general decrease with increasing plant output power. For instance CO may be given by an exponential form of the following type

$$CO = Ae^{-BW}$$

where A and B are constants and W output power. In case of coal the base cost CO includes the cost for FGD (Flue Gas Desulfuration) which is needed since most of the coal which may come to Puerto Rico from Colombia or U.S. have more than 0.5% of sulphur. The total base capital cost in BYI dollars is

$$C = (CO + K) = (Ae^{-BW} + K)$$

C2. Inflation and Interest

The base capital cost $(CO + K)$ should be multiplied by:

1. a factor which includes the effect of inflation from the date where the estimations are done (Base Year of Investment) up to the date when the plant construction starts. (Starting Year of Construction = SYC). This factor is given by:

$$(1 + i_f)^{Y_1}$$

where i_f is the inflation rate and

$$Y_1 = SYC - BYI$$

2. by a factor which takes into account, the inflation during construction of the uncompleted portion of the work, that is, the inflation on the material to be acquired at that given time during construction in order for the whole project to be finished. This factor is given by:

$$(1 + i_f)^{(1 - a)Y_2}$$

where Y_2 is the construction period in years and "a" the integral of the money to be spent during construction,

$$a = \int_0^{z_{max}} (Y_2 - t) dz / (Y_2 z_{max})$$

where,

$$0 \leq t \leq Y_2$$

and dz is the increment of expenditure at the time t during construction. The inflation rate i_f may change between the BYI and $BYI + Y_2 = FYOCO =$ First Year of Commercial Operation.

3. by a factor which takes into account the interest of the dollars spent during construction. This factor is given by:

$$(1 + i_{dc})^{aY_2}$$

where i_{dc} is the interest rate during construction.

Thus the total capital investment cost C is given by:

$$TC = (Ae^{-BW} + K) (1 + i_f)^{Y_1} (1 + i_f)^{(1 - a)Y_2} (1 + i_{dc})^{aY_2}$$

TC is expressed in \$/KW

C3. Fixed Charge Rate

The previous total capital investment TC must be recuperated during the life of the plant. A fixed charge rate will allow the utility to recuperate all the investment and some profit. The investments recovery factor may include amortization on a sinking fund type of account, property insurance, which is function of the capital investment, plant depreciation; a percent to cover property taxes, composite income taxes, charter licensing taxes, etc. In the case of PREPA the Trust Indenture requires that the electricity rate covers the cost of interest on bond issues plus amortization, plus a straight-line depreciation of investment. This helps to build up capital in order to provide an adequate safety margin to pay the debt. Such safety margin is calculated by dividing the net revenues (revenues less operating expenses) in a period of a year by the yearly committed payment of the debt. This ratio should be not less than 1.5. Thus, this safety margin, sometime called "coverage" should be greater than or equal to 1.5,

$$\text{Coverage} = \frac{\text{Net Revenue/Year}}{\text{Debt Payment/Year}} \quad 1.5$$

in order for the corporation to assure a good market for its bonds with low interest rate. In the case of PREPA (see discussion in II - 24 of reference I) the fixed charge rate (F.C.) will account for bonds interest plus the amortization in sinking fund or the capital recovery factor (CRF) plus insurance (INS). CRF is given by:

$$\text{CRF} = \frac{i}{1 - \frac{1}{(1 - i)^n}}$$

where i is the annual interest and n the plant life in years. (30 to 35 in most cases). Obviously the annual cost of the KWH will depend then strongly on this fixed charge rate (F.C) and also on the number of equivalent hours where the plant is at full capacity. To take into account this last important fact a capacity factor (C.F) is included in the calculation of the actual investment charge or cost/KWH. The investment Charge (I.C) equation may be written as:

$$I.C = \frac{(CO + K) (1 + i_f)^{Y_1} (1 + i_f)^{(1-a)Y_2} (1 + i_{dc})^{aY_2} (F.C)}{8760 (C.F)}$$

where,

CO = Base Capital Cost

K = Capital adders

$(1 + i_f)^{Y_1}$, account for inflation from the time of study to the beginning of construction

$(1 + i_f)^{(1-a)Y_2}$, account for inflation for the non expended money during construction

$(1 + i_{dc})^{aY_2}$, account for interest during construction

(F.C.) = Fixed charge rate = (CRF + INS.)

8760 = No. of hours/year

FUEL

F1. Fuel Cost

The fuel cost in \$/KWH depends very much on the type of fuel for the following reasons:

The cost (\$/KWH) is calculated from the product of the following factors:

- Price of fuel/unit = \$/lb or \$/barrel, etc;
- Heat value = MBTU/unit and
- Heat rate of the plant BTU/KWH.

For the same type of fuel different sources may result in different heat values, since this depend on the impurities and chemical compositions. We note also that for the same type of fuel different qualitates may require different adders whose costs are included in the term K of the initial capital C. For instance F.G.D system, land transportation facilities, port facilities etc., all there are elements to be considered and they should be part of the Value of K described in the section C of Capital Cost. It is also interesting to note the great difference in Heat Value for the different types of fuel. The following approximated figures may give us an idea of such differences.

<u>Fuel</u>	<u>(Heat Value in BTU/lb)</u>
Coal	10,000
Oil	20,000
Nuclear	40,000,000

F2. Levelized Fuel Cost

The fuel during the life of the plant may be subject to inflation. In order to compare the fuel cost and the capital cost both costs have to be reduced to the same basis. This is done by levelizing the fuel cost, that is calculating the constant cost which present values is the same as the integrated variable cost resultant from inflation process.

$F_L = F_o.L$ = Fuel Cost at the beginning of construction) . (Levelizing factor)

where

$$F_o = F_c (HR) (1 + e_f)^{(Y_1 + Y_2)}$$

and,

F_c = Fuel Cost in \$/HR= Heat Rate in BTW/KWH

$(1 + e_f)^{(Y_1 + Y_2)}$: factor which account for the inflation which occurs from the year of study to the first year of commercial operation.

The Levelizing factor L is given by:

$$L = \frac{(1 + r)^{n-1}}{r (1 + r)^n} \frac{i (1 + i)^n}{(1 + i)^{n-1}}$$

where,

n = life of the plant in years

i = discount rates usually equal to the interest paid on bonds for public corporations

$$r = \frac{i - u}{1 + u}$$

u = total average yearly inflation rate of the fuel.

OPERATION AND MAINTENANCE COST

OM1. O&M Cost

The total O&M Cost includes those expenses resultant from the staff cost, fixed and Variable maintenance, fix and variable supplies and expenses, insurance and fees, and administration and general expenses.

1. Staff Cost

The yearly O&M Cost of the plant at the FYOCO (First year of Commercial Operation) is given by:

$$TSC = \text{Total Staff Cost} = M.Pm. (1 + e)^{(Y_1 + Y_2)}$$

where,

M = Number of regular employees at the plant

Pm = Average annual cost per employee at the basic year of investment (BYI)

e = Average annual escalation rate

$Y_1 + Y_2$ = Number of years between the base year of investment BYI and the first year of commercial operation of the plant, FYOCO.

2. Fixed and Variable Maintenance Costs

Fixed portion of the maintenance costs hold in most cases a linear relationship with the staff cost. Thus FMC (Fix Maintenance Cost) is related to S.C (Staff Cost) by:

$$(F.M.C) = (a(S.C) + b) (1 + e)^{(Y_1 + Y_2)}$$

where a and b are constants to be calculated at the BYI (base year of investment).

3. Variable Maintenance

In general the variable maintenance cost (V.M.C) could be written as a linear equation similar to that of fixed maintenance. Thus

$$V.M.C = (a' (S.C) + b') (1 + e)^{(Y_1 + Y_2)}$$

where a' and b' are constants.

4. Fixed and Variable supplies and expenses

This cost includes all materials and expenses that are expendable such as chemical, lubricants make up fluids and gases, records, contract services, etc.

The fixed supplies (F.S) are generally proportional to the nominal power output (W) supplied

$$F.S = a'' W(1 + e)^{(Y_1 + Y_2)}$$

where a'' is a constant.

The variable supplies depend very much on the particular characteristic of the system.

5. Administrative and General Expenses (A&G)

This cost is generally proportional to the total fixed cost of O&M.

Thus,

$$A\&G = a'''(F.C) (1 + e)^{(Y_1 + Y_2)}$$

where again a''' is a constant and F.C is the total fix cost of the plant.

OM2. Levelized Operation and Maintenance Costs

Operation and maintenance costs are, like fuel, subjects to inflation during the life time of the plant. In order to compare all costs, capital, fuel O&M all of them should be on the same basis. For that we divide O&M cost calculated at the first year of commercial operation (FYOCO) by the number of equivalent hour of operation per year and multiply by the levelizing factor L defined in the fuel cost section.

$$O\&M_L = \frac{O\&M}{(C.F) 8760} L$$

where,

C.F = Capacity factor

8760 = hrs per year

$$L = \frac{(1+r)^n - 1}{r(1+r)^n} \frac{i(1+i)^n}{(1+i)^n - 1}$$

$$r = \frac{i - u}{1 + u}$$

u = average inflation rate during the life time of the plant
(n)

i = average interest during the life of the plant.

n = life of the plant in years

APPENDIX B

NEW DATA SOURCE

A. Coal Plant

References 2-4 were the main references used to put up to date the coal study. The main differences with regard to the data used in reference 1 are the following:

---the base year of investment (B.Y.I) is now 1983 instead of 1978

---the inflation rate is taken constant over the whole period from the B.Y.I. to the FYOCO (first year of commercial operation) and equal to 7%.

---the average interest rate is now 10% instead of 9%.

---the value of K (adders to the basic capital investment CO) was increased 30% with respect to the values used in reference 1 where costs were calculated in 1978 dollars.

---The fuel cost was taken as \$62/(metric Ton) FOB. At present coal originated in Colombia is sold to the Ponce Cement Co. in the Island at a price which is of the order of the one mentioned above. Its characteristics are approximately,

sulphur	1.5%
ashes	10%
heat value	10000 BTU/lb

B. Nuclear Plant

References 2 and 3 were the main source of information for the update study of the Nuclear Plant. The main variations with respect to the old study, reference 1, were the following:

- The value of A in the formula for the basic Capital Cost was increased in a 56.6% over the 1978 value of reference 1. This

assumption is based partially on the study made by United Engineering and Construction in 1981 (reference 2). There, the base cost of a 1139 MWE PWR Plant is estimated in \$1,135,361,396 which is about 46.% over the estimated cost of \$780,215,000 given in 1978 dollars by the same group in 1979 for the same plant (see reference 1 and reference 6). However EPRI group (reference 3) give a cost 1,115,000,000 for a 1000 MWE, LWR plant, which is about 56.6% over the 1978 cost of reference 1. We have considered in our calculations this more pessimistic estimation.

- The base year of investment is therefore 1981 instead of 1978.
- The O&M Staff members were almost double. The source of these data is the report of U.E. & C (reference 2). It reflects the new Nuclear Regulation Commission Policy after the Three Miles Island Accident. There, the security personnel are changed from 54 to 94, administrative services from 13 to 49, technical engineers from 22 to 50, maintenance crafts from 16 to 55 etc. These dramatic changes have obviously increased the Maintenance Cost.

We also increased the average yearly cost per person from \$24000 to \$30000.

- The inflation rate has been taken constant over the life of the plant and equal to 7%.
- The annual interest was also constant and equal to 10%.
- The fuel cost were updated using reference 2 and reference 7.

It is interesting to note that the item which increased most was the "spent fuel ship and disposal" respect to the 1978 prices,

however the ore cost was about half of the 1978 price. For this reason the price per Million BTU remained in the range of \$0.7 - \$0.8.

Oil Plant

The main variations in the oil estimations with respect to the study done in reference 1, were the oil price which was taken as a variable ranging from 27 to 30 dollars/barrel in 1983.

It is interesting to note that at \$30/barrel the cost of oil only, in \$/KWH, is almost double of the total cost for a nuclear plant. In fact the cost of oil without any other item as operation and maintenance and capital is about \$0.120/KWH while the total cost of the nuclear plant (fuel + O&M and Capital) is about \$0.050/KWH. The value of the oil must decrease to about \$13/barrel for the oil to be competitive with nuclear. At this point if no increasing in power is required in the Island, no new alternative is needed to be considered. The value of \$13/barrel is obtained in the following way:

The levelized fuel cost (L.F.C.) is given by:

$$L.F.C = \frac{9200P_L}{6 \cdot 10^6}$$

where P is the price of oil per barrel and L the levelizing factor. Assuming the interest = 10% and the inflation rate = 7% and 35 years of plant life, then L = 2.3. If L.F.C is equal to \$0.047/KWH, which is the total cost of the nuclear plant (see figure 1) minus about \$0.003 of operation and maintenance for the oil plant, then P is equal to:

$$P = \frac{0.047 \times 6 \cdot 10^6}{9200 \times 2.3} = \$13/\text{barrel}$$

- In all estimations, the interest rate and the inflation rate were taken equal to 10% and 7% respectively.

Photovoltaic

One of the references for the update study of the Photovoltaic Alternative was a 1983 price list of Duane's Solar Energy Co. (reference 8) according to which the peak-watt of a Solarex electric panels is sold at approximately \$12.00. According to reference 9 Arco Solar had submitted a bid for a 1.2 MW photovoltaic station at Sacramento with a peak-watt cost of about \$6 and the same Solarex Co. has completed a 2340 m² photovoltaic system rated at 200 KW at \$8.5/peak-watt. This Company predicts that in 10 years the price will come down to about \$1.7/peak-watt. These data and the same reference 1 were used to estimate the following peak-watt price-schedule from 1982 to 1992.

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
\$	8.	6.	5.	2.5	2.	2.	1.8	1.6	1.5	1.5	1.5

We should remark that this table is by no means a reliable source. But we feel that at this time, with the scarcity of data, is as good as any other prediction.

Biomass

The base constant A for the Capital Cost was estimated from the work of John M. Perkins and Wendy L. Rundle (reference 10). It results equal to \$1750/KW which is about double from the 1978 price used in reference 1.

The fuel cost of \$1.85/Million BTU was obtained from the work of Alex G. Alexander (references 11 and 12). This price includes all costs: land rental, cultivation harvest expenses and transportation. Since biomass requires a much larger and less efficient boiler than coal the heat rate for the boiler was increased from 10000 as used in reference 1 to 15000 BTU/KWH which is more in agreement with reference 10.

To obtain the curve B, of figure 1 (and also the values given in table 1) we have assumed that O&M costs are equal to those of a coal plant with FGD. Actually the burning bagasse will not rise any sulphur problem, however this assumption has been taken as a criterium to account for the extra staff and storage and a much heavier transportation required in the managing of the biomass fuel.

Wind

The base cost of 1755.33 of reference 1 for a 1.5 MW plant in 1979 dollars, was increased to \$2000/KW, much in agreement with reference 10 which was published in 1983. Most other items were left unchanged respect to those of reference 1, except that we used a constant inflation rate of 7% and interest rate of 10%.

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