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CEER-X-72

ENERGY ANALYSIS

AND SOCIOECONOMIC CONSIDERATIONS.

FOR PUERTO RICO

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With Specta' Contributions by.

May 1980

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CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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CEER-X-72

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By:

With Special Contributions by:

May 1980

CENTER FOR ENERGY AND ENVIRONMENT RESEARCH

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U.S. DEPARTMENT OF ENERGY

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and 7 1/W8/ye all costs

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all costs, 7 1/4t/yr. Uj0g and

dye. all costs

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Fuel Oil Power °lant vs Start-up

year. Escalation at Si/yr. except

Fuel Oil at 9/sr.

Levelized ?fozal Costs for a Two

450 M8 ?nit Fuel Oil Power Plant

vs Start~vo Year. Escalation at

St/ye. excepe Fuel Oil at 9/yr.

Total Levetized Generation Costs

of Powr Produced by Nuclear, Goal

and Fuel Oil units. Escaiation

at Sty.

Total Levelized Generation Costs

of Power

Total Levelized Generation Costs

of Power Produced by Nuclear, Coal

and Fuel Oi! Two-Unit Plants: ES~

Total Levelized Generation Costs

of Power Produced by Nuclear, Coal

and Fuel Oil Two-Unit Plants: ES~

calation at 7 l/atiye.

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Power Produced by 250 Me OTEC Plant

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of Pover Produced Sy Biomass Plant

Escalation st St/yr.

Total Level zed Generation Gost.

of Poser Produced by Bionass Plant

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DOE Photovoltaic Program Modsle/

array Price Goals and History

(1980 dotiars)

Total Levelized Generation Costs

of Alterns:ives For Electrical

Energy Production in P. R.

Escalation Si/yr.

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of Alternatives for Electrical

Energy Produc:

Escalation 7 1/4u/ye.

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SECTION 1

STUDY PURPOSE, RESULTS AND PROPOSED PROGRAMS

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Section 1

STUDY PURPOSE, RESULTS AND PROPOSED PROGRAMS

1.1 untrooucriox

?The Governor of Puerto Rico has recognized the seriousness of the energy situation by establishing an Energy Office and by approving the Energy Policy document during 1979. Rapidly changing oi1 prices

and fuel

availability wil! seriously affect the velfare and socio~ economic development of the Island if no adequate energy alternatives

are found in the near future.

The President of the University of Puerto Rico (UPR) has recognized the need of circecting weil planned efforts tovards the development of onergy alternatives to compete with comerciatly avail- able sources of enersy. Late in 1978 the President urged the Director of the Coneer for Energy and Environment ?Research (CEER) to initiate energy aysten analyses and assessments of alternative energy scenarios and to identify the most promising and economically viable energy alternatives in accordance with the Energy Policy document. This vas

4 wide-ranging and ambitious ¢

ky and the present document is a

product of the study.

?This Energy Study beging with an analysis of the energy requirement projections up to the year 2020. The cost of electricity produc fed by commercially available oil, coal and nuclear plants located in Puerto Rico is analyzed for the same period. Tt vill be seen chat electricity fron nuclear plants has the lowest cost. However, the low cost of electricity produced by nuclear plant:

as determined by the Study, is not used as the cost criteria which the other energy alterna~ tives must achieve to be considered attractive for development and

comercialization.

Today nuclear plants are associated with socio-political problems

at the national and international levels. Mainly for this reason,

me

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scenarios involving nuclear plants are not endorsed by the Puerto Rico

Energy Policy Document.

1.2 sTupY RESULTS

The Study indicates that electricity produced by nuclear plants

is Less expensive by a significant factor, in the order of one and one

half to two, than the electricity produced by commercially available

coal plants. The Study shows that the cost relationship will be

paintained for

12 rest of the century and beyond, High estimates of

nuclear plant capital investment and fuel costs were taken from

available commercial data.

Coal plants are recognized as a viable alternative in the Puerto Rico Energy Policy Document. The cost of electricity produced by coal burning plants is used as the cost criteria which must be achieved by other energy alternatives for them co be considered as attractive for development and conmercialization. The impact on the Islané?s economy of coal importation for the coal burning plants versus the impact

of other energy alternatives such as OTEC, biomass ?and direct solar energy provide sone socio-economic credit in favor of these renewable energy alternatives. ?This impact is analyzed

Chapter 5 and is summarized at the end of this section.

OW fveled power plants are the highest cost energy alternative

analyzed in the Study. The use of this alternative should be minimiz

fed with a strong, dynanic and aggresive alcernative energy developoent

Program.

Excluding nuclear plants, the lovest predicted cost of electri-

8

escalation rates of 8% per year until 1985, the average production

city results from power plants burning biomass. With acsu

cost for the first year of electricity froma biomass fueled plant is

predicted to be 6,58 cents per kvhr, and with an assumed escalation

of 5% per year beyong 1985, the levelized cost of electricity during

the Lifetine of the plant (assumed to be 35 years) is 7.13 cents per

---Page Break---

lhe. By contrast, the corresponding costs for @ coal plant equipped

with 2 Flue Gas Desulfurizat

for the

(FCO) System is 6.35 cents per Kehr

rst year of operation (1985), and 9.59 cents per kubr lev.

ized cost for the lifetime of the plant (1985-2020). The correspond-

ing cost of electricity from residual fuel oil burning plants shows

costs of the order of 1607 and 3202 of those for the coal burning

plant. (Oil fuel costs of $57 per barrel are assuned for 1985 and there is 2 9% per year escalation thereafter).

?An Ocean Thermal Energy Conversion (OTEC) plant of 250 ¥i) capacity is show to be economically competitive with coal by the

riddle of next decade, An initial OTEC pilot denonsteation project of 40 My capacity scheduled to begin operation in 1985 is show to

bbe non-cozpetitive with coal, but it will have electricity costs much

lower than the

#5 of electricity produced by oil fired steam plants.

4.250 Mi photovoltaic central power installation with electric battery storage projected for operation in °sy3 is show to be highly

competitive vith coal burning plants. Photovoltaics is energing

very attractive possibility for the Puerto Rican scenario and offers a very attractive alternative in case there are difficulties with the OTEC program. Before this Study was undertaken, the competitiveness of photovoltaics was ?ho

to be 20 or nore years auay. Now it seems that Photovoltaics can be pushed to econonic competitiveness within ten years through an adequate Research and Development (RED) Program. All of the electrical energy generated last year in Puerto Rico could have been generated with solar photovoltaic facilities ?equipped with olectrical battery storage and with a total cell surface collection area of less than 1% of the area of the Island at costs predicted to be similar to coal and initially lower than the costs predicted for OTEC power plants. The technical problens associated with Photovoltaics becone rather simple when compared with the tech nical problens associated with OTEC marine plant facilities, A

photovoltaic manufacturing industry would be more feasible for Puerto

m3

---Page Break---

Rico

rm would an OTEC manufacturing enterprise. On the other hand, OTEC has no impact on the use of land resources which is a great advan~ tage for Puerto Rico. The economic attractiveness of these two

altematives, plus the particular advantages of each alternative point

towardsa judicious and balanced decision to explore both alternatives

equally.

Electricity generated from vind pouer generators, the other alternative studied, is shown to be not economically coapetitive (by

4 factor of 2) with electricity produced from coal plants, but it is capable of producing electricity cheaper than ofl burning power plants. No storage systen was considered in the econonic analysis of wind power generation systens for central pover stations, This would make he wind power system even more expensive. The Study

therefore, shows the central wind pover system to be switable for fuel

81 displacement, but not as an economically viable base (with storage)

energy systen.

?The suleiplying beneficial economic effects of reducing oil imports by the use of renewable energy alternatives is analyzed in Section 5 of the Study. Figure 1.2.1 "Total Levelized Generation Costs of Alternatives" illustrates the predicted production cost of electricity fron the alternatives considered. The levelized cost indicated is the ?average? cost during the 1ifetine of the facility with the inflation of operating costs and fuel costs taken into consideration.

nis levelized cost is plotted against the start-up year, i.e. the year that the facility will start commercial operation. The later # facktity is comissioned, the higher are the investment charges due to inflationary factors. However, once a facility is commissioned, the annual investment charges for that facility are not

penalized with inflationary factors

ince the money is supposed to be

sunk" at a specified and fixed bond interest rate. Operation and

aintenance charges

well as fuel charges, if any, will continue to

escalate during the Lifetime of the plant. These charges are taken

care of by the Levelizing factor.

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FIOURE 1.2.1

AM Coss escoleree ot S1/4%/ Yr except Fut! Ol) ubich In

?scelared 01 94717 and Yellow Cake in carte 2 61 TINK? Ye

TOTAL LEVELIZED COSTS (nille/ wn)

af Wind enray atrerzenive inter serge) show fer compe

purposes wih Poe! Olt Cont component carve

BS

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The prediction of investment charges for alternatives that are

not connercially available and for which no cost investnent experience has been accumulated is based mainly on the use of industry learaing curve cost predictions and market sales predictions nade by the Department of Fnergy (DOE).

Chapter 5, "Socio-Economic Analysis", contains assessments of the impact of ofl price increases on Puerto Rican industrial sectors ?and of the impact of enploynent and productivity outputs for two

selected alternative energy sources.

increases will impact severely on the econony of Puerto

Rico. Costs increases to industries such as cement, electricity

on, construction,

ning, alcoholic beverages, transportation and business services vere tramendous. The results show that the

Jargest Sucl fs in the daportant industries in terns of out

Put generation ang job creation. This study shows that, al! prices

ase in oil prices from 1973 to 1979 (assuming @

conservative price of $21.00 per barrel of crude in fiscal year 1979)

constane, the inc

will induce or have already induced an increase of more than 130% in

an estinated producers price index (excluding industry mark-ups) .

This implies double digit inflation even when there is no inc

in other prices. This increase has resulted in an estinated loss of

58,000 jobs and $1,328.2 million in productivity. The prospects for

the next five years (to the end of 1984) look no better. The failure

to establish a vigorous and aggresive research and development progran

on energy alternatives for Puerto Rico does not hold any hope for an inproved energy situation in the near future.

Nevertheless, the second part of the socio-econamic study in chapter 5 was based on the assumption that such a vigorous and aggre~ sive research and development program had been put into action and chat the Biomass and OTEC alternatives had been made economically conpetivive for the time predicted in this study. The impact on employment and output productivity of these two energy alternatives was evaluated by

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the use

ontief's open input-output matrix mode, Since the price index structure of 53 economic sectors made by the Puerto Rico Planning

Board is based on 1972 prices, that year vas used as a reference basis.

Yor two 300 Mi each Biomass Plants and one 250 MW OTEC power plant the study indicates an increase in employment of 67,145 workers and an increase in productivity of $1387 millions. This assune that the reduction in Suporte will improve the balance of trade, which in turn will increase domestic {inal denand. The unemployment rate, with ether factors constant, could be reduced by about 7% from its 1979 evel.

?The halt placed on the rising production costs of goods and services (including electricity) fron higher fuel of2 costs was not

taken

10 consideration in the above result. As nentioned earlier, che inpact of higher petroleum costs from 1972 to 1979 has been estinated to have caused the loss of $8,000 jobs and $1328.2 millions An productivity. When both factors are taken into consideration,

the inplfeations to the socio-economic well being of Puerto Rico are far-reaching. The dollars spent today by the Puerto Rico Government in a significant RAD program for energy alternatives will show iport- lant results on the socio-economic picture. Adequate attention has

not been given to this subject up to the present tine.

tn general, the analysis presented in this study is unique

1s on the tine schedules and prograns required to

advance energy alternative systems from economical and commercial

because it focu

points of view.

1.3 ELECTRIC POWER SCENARIOS

Based on these econonic analyses, alternative energy scenarios

ccan reasonably be prepared for the rest of the century. Corresponding

R&D programs and funding requirements can be developed on a voll

planned, timely basi

---Page Break---

on the present state of development of the various technologies and Crom é potential of the various alternatives to compete

he predict

economically with coal, che following program is envisioned:

1. Biomass 2rogtan

A strong progtam iv requized cw make the first (OM450 mM)

Power plant operational oy 18h,

otc Progran

an

gresive propran is necdet to make the first experinent=

Sent {49 i) operational by 1985 and first commercial

pleat (250 MW) operational by 1991.

hotovoltaic Program

A dynamic progran is needed so that a larse denonst ration

project can be placed on operation by 2

Powcr Turbine Generators

A Program coupled with the operat ions! experience of Culebra's

Wine Turbine is required so that a 12.5 Hi wind power turbine

farm can be placed in operation by 1988, for fuel oli dispiace=

Based on eatinated needs for additional electrical generation

capacity as described in Section 2, a possible scenario nas been

Prepared based on the energy alternatives with econonic potentials

determined by the Study,

?8 scenario is indicated in Table 1.3.1,

The sconario fits approximately the base load generation requirements

eeseribed in Table 2.

+Sb of Section 2, No attempt has been nade to

substitute existing fuel oi! generating plants with energy alternative

systems, but rather an anbitious scenario is shown allocating new

Beneration requirenents to the renewable energy alternatives that are

economically competitive with coal.

As seen from Table 1.3.1, three coal burning plants, one with

300 MW capacity in 1985 and two with 400 MW capacity each for 1989 and

1990 are included in the scenario, It is estimated that bionass burn

ing plants can be placed in operation as early as 1986 and 1987. No

additional dionass plants are indicated because agriculture policies

Le

---Page Break---

Year

1980.84

1985

1987

1988

1989

1990

1991

1992

1993

ro94

1095

1996

1997

1998

1999

2000

Biomass

1300MW

+300MW

TABLE 1.3.1

oTEC.

1.40mw

1.250MW

250M

10250mW

1-500MW

¥-s00mW

1

Photovoltaic

1-260

1-250MW

Wing

200KW

1asMw

SCHEDULE OF PROPOSED SCENARIOS PROGRAM OBJECTIVES

ELECTRIC PLANTS CAPACITY

Coat

1-300MW

400M

1.4000

---Page Break---

fare wwiefined at this time. The evo 300 MY bionass planes will require

the planting and harvesting of approximately 75,000 acres of land, about

the tand acreage actually devoted to sugar cane in Puerto Rico. Coal

and bionass plants should be designed to burn either fuel.

No more than 500 Mi of power from photovoltaics is shown in the

scenario because Land usage polics

sre undefined at present. It is

estimated that the two 250 i photovoltaic installations will require

approxinately 10,000 acres of land. To generate with photovoltaice

all the electricity produced in 1979 in Puerto Rico a tetel land area

of approximately 100 km square or 25,000 acres would be required.

A wind power farm also has the same type of land requirenents. The 12.5 MV wind power installation which is evaluated in the Study will require approximately 3000 acres. For these reasons the scenario depends heavily on the OTEC alternative. However, not all the efforts are placed on this alternative because it still has many questions to be answered, The scenario does not present any fixed alternative to be followed, but rather provides a reference alternative on which to dase the requirenents for R6D Programs.

Table 1.3.2 represents the possible savings in equivalent willions of barrels of oil that can be achi

ved with the proposed scenario.

Table 1.3.3 illustrates the estimates of energy requirements for Puerto Rico to the year 2000 under the present socio-economic structures with the absence of strong R&D program on alternate energy sources.

A second scenario with lesser consumption projections is calculated in Chapter 2. However, the higher consumption scenario represented in Table 1.3.3 reflects a more difficult situation.

The total fuel ofl consumption for electrical generation between the year 1985 and the year 2000 from Table 1.3.3 is 881.9 million barrels.

The savings proposed by the scenario indicated in Table 1.3.2 represent only 22% of the energy savings during the period. This further indicates that the energy situations is so dependent on oil that heroic efforts are

required to make even a slight reduction in oil importation during the present decade.

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Year

TABLE 1.3.2

POSSIBLE EQUIVALENT MILLIONS BARRELS OF O1L

SAVED WITH PROPOSED SCENARIO AT 75% CAPACITY FACTOR

Biomase

(ition Barrets)'st

orec

me

Photovoltaic Wind!*!

SE _Prtovcitic Winall?

198084

1985

1986

1987

1988

19

1900

1997

1992

1993

1908

1995,

1996

1997

1998

1999

2000

3.285

687

687

687

657

657

6s?

657

697

657

esr

687

687

657

687

438

438,

a8

438

438

438

2744

5.48,

5.48

322

322

322

822

1370

19.20

19.20

09

09

09

09

: 09

274 09

274 09

548 09

548 09

5.48, 09

548, 09

5.48 09

5.48 09

SS

Totals:

95.265,

101.308

(@) Assuming 600 kwh/BBL

(0) Energy calculated from available wind and turbine characteristics

(0) Assumes 40MW- OTEC Exp. is shut down

38.36 17

236.103,

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TABLE 1.3.3

ESTIMATES OF PUERTO RICO'S ENERGY REQUIREMENTS TO THE YEAR 2000

UNDER PRESENT SOCIO-ECONOMIC STRUCTURES WITH AN ABSENCE OF

STRONG R&D PROGRAMS ON ALTERNATE ENERGY SOURCES

Million Barrels of Oil Imports For

Electrical Gasoline Industry Estimgted Unit Total Cost

Year Eneroy(#) & Diesel) g Other (©) Total Price S/BBL 8) (S Millions)

eee ilors)

1976 oa? 76 3a

1977230 13200 S627

197824 165-38 65.0

1379260 70281811470 1001.

1980275 7S 31678 1203

181.290 5 2777521817 1442

1982 20.7 120281778 21.90 v704

1983 a9 198 = 00522 25.00 2055

198 33.6 205 208681285 2458

1985 35.3 20 36 = 8993270 2959

1988 367 24 3538629, 3390

1987-379 29° 74 9890.28 3903

1988422 25 389 1036 44.72 4633

1989448231 409 1088 49.60 5396

1990 474 236 429139 55.00, 6266

r901 S08 240 © 451 1199 58.75, 7048

1992534 25 473195262. 7856

1993 56.0 25.1 497 1308 +6700 9205,

19000. 27 5221370 71.80 9706

1995620 20 8 48 | 1a2B 7650 10924

1996 5.0284 575 1489 an.t2 12078

199763 267 604 155.2 86.00 13347

1998718 74 634 162.3. 14793,

1999744 279 «6661686 96.62 16290

2000776 28.1 699 1786 1026 18016

toa 315,820

{a} Statistical Correletions between population and GNP, and between GNP and

Electrical Energy Generation, Correlation 997

{b} Garoline Consumption growth projected conservatively between 2 1/2 ~ 3%

er year vs. 6.6% actual growth,

(c) Industrial nends projected at 5% per year growth,

(3) Fuel oll prices escalation indicated is approximately 1980-85: 14 3%/year;

1985-90: 11% year; 1990-95: 6.8%4/year and 1995-2000: 6 yeor

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ELECTRIC EXERGY CONSIDERATIONS

?the Une principal non-electrical generation energy alternatives

fron a scale viewpoint which are addressed in the Office of tnergy

Document "Polftica nergética de Puerto Rico? are:

4. Solar industrial steam and hot water

by Fuel synthesis

©. Conservation measures, mainly in transportation.

Preliminary considerations have been given to these topics in CHER docunent A-31, "Preliminary Report on RED Program Needs for Enerey Alternatives in Puerto Rico" (June 1979)?,

te As estimated in the CEER-X-31 report that ethanol and indus~

trial solar steam can play a substontial role in reducing oil fuel

imports. An electric generation project based on photovolt.

Wes can

be designed as a co-generation project (solar steam production and electricity). It has been estimated that a 250 My electric photovoltaic

cogeneration project can produce enough industri:

steam to save the

equivalent of 3.7 million barrels of oil per year.

Industrial ste

fan be produced separately by adequately design-

ed solar concentrators. It has been estimated that solar steam

production equivalent to the savings of six million barrels of oil per

year can probably be achieved with a strong R&D effort.

Ethanol is a potential help for the transportation industry. A

Proposed CEER project on ethanol to be undertaken at the UPR Rum Pilot

Plant has been submitted to DOE. An ethanol project can be economically

designed as a cogeneration facility to provide stea for its om needs

and to generate electrical energy from baggase. Preliminary estimates

in

cate that a savings of 7.5 million barrels of oil per year can be achieved with ethanol production,

Energy conservation measures in the transportation industry

require special attention. 1t is difficult, however, to assign specific

---Page Break---

figures co this program, but it could reach savings

high as 5-102

fon oil imports.

le 1.4.1 indicates the combined total savings which covld be

obrained through an aggresive R&D effort. In the electrical sector the reduction in fuel ofl barrels equivalent is over 26%, and for all

vectors the fuel ofl barrels equivalent reduction is approximately 212.

in transportation are adéed, probably a

5-102 additional reduction could be achieved.

hen conservation measurt

All of the above indicate that a strong ROD effort in Puerto

Rico can achieve an approxinately 1/3 reduction in oil dependence while

still maintaining the sane level of economic development.

TABLE 14.1

POSSIBLE MILLION BARRELS OIL EQUIVALENT SAVED

WITH PROPOSED SCENARIOS AND A STRONG RAD EFFORT

Tac Seon Ton Be

a vata

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ss 8 See

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oo ?oe ® ie te it

oo ?ss rt Crt

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cr ba ® fe arte

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os tom brag

ss; obama gt

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1,5 RESFARCH AND DEVELOPMENT (RED) EFFORT REQUIREMENTS

Tn order to make possible the pronpt development of alternative

energy sources to fit a scenario

inilar to that proposed in the

Previous sections, appropriate research and development (R&D) efforts

are required. Such RSD efforts must be coupled with the corresponding

velopment possible.

demonstration projects to make timely

?The minimum basic scientific and technical information necessary to address the exanple scenarios proposed to fit the Office of Energy docunent on Public Energy Policy are described in the document CEER-SS "Proposed Five Year Plan-Energy and Environmental Programs," Draft No.1, Decenber 1979.°? A summary of the basic research program described in above docunent is given in Table 1.5.1, To address the demonstration Projects thenselves, RSD funds in the order of 5-72 of the total capital investnent would be required. This figure falls within the historical percentage of capital investment assigned for R&D by lorge ?companies such as Corning Glas

?The RD for the OTEC demonstration project has been increased to

double (12.52) the indicated historical requirement in order to provide for expensive marine work and to make the proposition for securing balance of funds from DOE more attractive. Table 1.5.2 summarizes the RSD requirements for large denonst ration projects.

The funding for the basic minimum research progran summarized in Table 1.541 mst be borne by the governnent. Table 1.5.2 illustrates the capital investment requirements for large demonstration projects. Table 1.5.3 illustrates the RéD funding requirements for the denons~ tration projects shown in Table 1.5.2. It is assumed that the R6D funds described in Table 1.5.3 are included within those of Table 1.5.2. The funding for the R6D for large denonstration projects as described in Table 1.5.3 can be borne in part by the user institution Project budget, by a consortium of private concerns, and/or in part by the government. The discussion of cost sharing formulas is outside of the scope of this work.

rs

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TABLE 15.1

TOTAL R&D EFFORT REQUIREMENTS FOR GOVERNMENT FUNDING

(1980- Thousand Dollars)

ee

198219831984 19851986 Tota!

1 oTec* 2200 2800 3,200 3200 3,400 © 14.800

Hl Blowass* 4150 2.190 2380-2380 2.280 © 13.320

Hi SOLAR ENERGY* 828 951.235.1507 1.710 6275

IV. GASOKOL 220 © 220 225-240 905,

V. TRANSP.CONSV." 625 3675 «633_?=sB70 387.5258,

Towa 2023 65125 7.673 7.897 7.7775 37,883

???. eee

* Funding for these programs is the same as in CEER Year Plan (Draft 1)

?The revised CEER 5 Year Plan (Dratt 2) indicates a considerably reduced program

?budget due to economic restraints. Such a reduced program budget is not considered

adequate for an agressive attack on the energy problem,

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TABLE 1.52

CAPITAL INVESTMENT IN DEMONSTRATION PROJECTS:

(With R&D Efforts in Table 1.5.1)

(Private industry, goverament corporations, consortiums,

(and government sponsored business investments)

?

Investment Cost

Project Capacity Scheduled {million dotlars)/¥r

oTec (@) aomw 1985 $ 209.2 (1980)

otec(250NW 1991

?aromass'*? 00K 1986 168. (1978)

PHoTovoLTAIc!®) ? 260mw 1993 1.126. (1980)

WIND ON SCHEDULE

ETHANOL PLANT!) 100 millions gals.

FOR GASOHOL per year Ethanol 1986 228°) (1978)

STEAM cocEN(b)

2) With Ethanol 33 million

Plant pounds per day

350 F Steam 1986 250. (1978)

I With Photov.!®) 2.2.x 10"?

Plant Btu/year or

60 million

pounds per day

350° F Steam 1993, 44a (1978)

{a} From Chapter IV this report

tb) From CEER X-31

{ec} Using existing sugar mills, costs might be half of those indicate.

Tat

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Tonviaa

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W131SAS TYNOLLN3ANOD WWAN (sacsuiow9t

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g Arprewxordety)

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SLVINILS3 13!

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YANCLIGSLONS? AND RECOMMENDATIONS.

1.6.1 Cone

Biomass vromises to be the most economically attrat~ ive short term energy alternatives for central electric stations vith costs lower than coal power plants as early as 1985. The needed technological developments for biomass systems require the feast effort of all the alternatives,

OTEC and Photovoltaics promise to be competitive with coal central pover plants with costs similar oF slightly higher (less than 12) than predicted costs of electricity from coal plants as carly as 1994, Both alternatives require substantial tech= nological advancenents.

ind energy systems without storage can be used economically for fuel oil displacesent, but they are not economically conpetitive with coal power planta.

Nuclear power wil! continue to be the lowest cost

Power for the rest of the century and beyond.

?The Socio-economic implications for Puerto Rico for the development of local alternative energy sources indicate benefits in the range of billions of dollars of annual increases in productivity and reduetions in unemployment by over 72.

1.6.2 Recommendations

L

Strong R&D prograns should be implenented to make

Possible the use of bionass in planned coal pooce plants by the mid 1980's.

OTEC and Photovoltaics R&D program efforts should be Geveloped to make these alternatives econonically viable in the Puerto Rico scenario by the mid 1960's,

Solar steam and other energy conservation prograne Such as ethanol production for gasohol, hybria vehicle research programs, transportation managenent

and policy studies should receive detailed consiaers~

Energy Analysis studies should be continued and

updated yearly and should be based on the latest

economic trends. The equations developed in thi

work should be programed for conputer, paraneceie

and sensitivity studies. The summary of the rescies

with comparisons of previous year's analysis should

be published.

mg

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SECTION 2

LONG RANGE FORECAST OF PUERTO RICO ENERGY NEEDS

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Section 2

?ONG RANGE FORECAST OF PUERTO RLCO"S ENERGY NEEDS

1 ELECTRICAL ENERGY FORECAST

2.bt Introduction

?The problen of forecasting long range estimates of energy

usa is a difficult task because of all the uncertainties involy-

the development of row technologies and because of changing

habits which will affect the estimates considerably. An attempt

ras Seen made to forecast for a period in which present enbryonic

technologies could be extrapotated in e qualita

re sense. A

49 year period, tv the year 2020, 41

believed to be long enough

to provide fer such an extrapolation and to provide energy planners with an overview of the next four decades for the focus~

ing of energy alternatives.

CEER interest is main

in the energy ané fuel alternatives scenarios which are required to pover socio-economic development in Puerto Ricoy

therefore the forecasting has been restricted to the total electrical energy generation which is responsible for

ese fuel consumed in the electrical plants.

Classical statistical regression analyses were used for predicting electrical power generation requirements." A sinple approach was adopted so as not to complicate the prediction with complex relations and hypotheses. The prediction for non-electrical energy requirenents such as gasoline and industrial

fuel of1 requirements were based on an assumed per cent growth

per year considering historical consumptions.

sstatictical Yethods for Decision Yaking, W.A. Chance 1969.

TRAIN=DORSEY LMTD., Mokeleton, Ontario

me

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the peedi

ion of electrical energy generation requirements

£5 based on two main factors:

a, Population

b. Beononic velfare or per capita income of the population,

?These factors were statisticatly analyzed before the predictions were made. After the mathenatical relation= 8 were established, judeenents of past experiences

ang insights into new technologies and changing habits were considered 0 that the nost appropriate relationships could be selected.

?the tnergy prediction will be baved sizply on o correlation between tie total CNP at constant orices and the electrical energy consumed. The C8P wilt be predicted from the product of population predictions, tines tie

125. Populations

Gue/eapita prediction at constant pi

have already been predicted by the Planning Board up to

?the year 2000 and the ONP prodicted to the year 1983.

our predictions will be, therefore, somewhat uncertain

for the period 2000-2020.

2.1.2 Ropulacion

Population ie a very sensitive variable in the predict=

ion of energy needs, Different governnent programs,

welfare programs, and social and religious attitudes may

influence population growth to a certain degree.

Melendez indicates that the growth rate of the economy

of a nation responds hetter to a mderate increase in the

population than to a rapid growth rate as is the present case

Puerto Rico vhere population is doubied in las than 3 years, Sconferencia sobre Econonfa y Poblacién, Dr. Janes A. Santiago Meléadez

Serie de Conferencias y Foros: NGm. 4 Departanento de Economfa, Universi~

dad de Puerto Rico, Rfo Piedras, Puerto Rico.

2

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oF to @ sicx nonulet Lon growth vate such as doubling of

population evry 200 years. A doubling tine in "he

order of 50 yoars is considered adequate to help econon':

growth.

A rapid population growth rata causes severe impacts

fon the nation?s substructure and on the balances of

resources, und requires higher investments fron outside

Sources. On the other hand, 2 very slow population growth rate can create @ problem when the population matures ond he

are not enough youths to replace those leaving the Labor force. This has been experienced in certain areas of Japan. However, the concept of optimal

population groweh is difficult to determine because of the many factors involved.

The Planning Boare has predicted a population for Puerto Rico of 4,675,000 for the year 2000. City by city predictions have been nade up to the year 2000.

?The population of Puerto Rico in 1960 was approximate Ay one half of that predicted for the year 2000, thereby indicating a doubling of the population in this 40 year period.

Using a Linear regression analysis on historical

population data going back to 1962 and using the Planning

Board predictions to the year 2000 as input data to the

regression analysis in which the total nunver of input

points is 22, the following equation resulte:

Yp * 2166.9 + 65.05 x

where y, = population in thousan

x = year referred co 1960 i-e., year less 1960.

ina

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Adicating a rigaitie-vt cor-etation of 4

The predicted powwtstion culeulats

In this maccer for

the yesr 2020 will be 6,070,110. The opproxénate doubling

vine of the present escimazed populatior of 7,338,000

above Usear cel

using conship is 51.3 vears, This

Inge for an adequate eeonoaical

growth as devined by MeLéndes.

An exponent ial regression of population was also attempted. The exponential relation gave the same degree

of correYation ang coefficient of deternination as the

Miner retat?onsiip but the doubling time forthe present

poputs

was 35 years. Since this should not be the

goverament seliey, it was di

carded. Tre exponentia?

relationship was

population equals to 2308.65, times

?eM elevated to the exponent 0.02%, x having the same

waning as before.

The predicted population for che year 2020 with ehis

exponential relation vas 7,300,580. This was discarded

in favor of the more appropriate Linear correlation

indicating a 6,070,110 population in the year 2020,

?The predicted population data to be used in the

study is given in Table 2.1.2

Econonic Welfare

Te will be as

waned for the study that the overall

?economic welfare of the country will be maineained and

improved. The Cross National Product (GNP) per capita

in constant dollars is a measure of this index. Therefore,

AE the total econoaie welfare of the country is to be

improved, the GNP per capita in constant dollars shou?d

---Page Break---

TABLE 21.2

POPULATION BY LINEAR REGRESSION MODEL

Population

Imitions)

347

353

3.65

372

3.78

3.92

426

492

467

5.09

542

5.75

607

rs

---Page Break---

reflect a small or soderate yearly increase. The total Ont?

in constant dollars should chen refs

8 yearly increace

in the rate of ONP per capits at least equal to the popul

tion growth rate. The total ONP in current dollars shoul:

further reflect any increase due to the inflation price factor.

?the Gross National Product (GNP) suns up the economic activities of the country in terms of the production of goods and services, The total consumption of electrical ?energy by all sectors of the economy is very sensitive

co this variable and can therefore be satisfactorily corre- lated, Statistical tests can determine how good the corre

lation 4s.

?The Planning Board has predicted total GNP values in current dollars up to the ¥#
Table 2.1.3 below.

© 1983 as indicated in

TABLE 2.1.3

ECONOMIC INDEXES.

(Planning Board Predietion of GNP)

(Current Dollars in Millions)

1979 1980 1981 1982 1983

Current $ 9835.0 107500 116930 127100137950

Constant $ 4047.4 42088 © 4589.7 48140 5090.1

constant dollars vere estimated by assuming a 10 point

increment in the price index for the year 1979 and a 7 point

increment for each of the renaining years. The 1978 GkP

price deflator factor relative to 1954 (he year that the

Planning Board used to reflect constant prices) is calculat~

ed to be 233 from the Planning Board reports on current and

6

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2d

lonstant dollars di

eing the predicted popylat fons

for the years 1979-83, the above GNP in constant dollars was converted to GNP per capita,

?The data together with historical data back to 1962

were then analyzed by statistical methods. Four types of

regression analyses were tried, in:

ding Linear,

exponential, logarithmic and power. The best fir corre-

lated with a 97.5% correlation coefficient or 95% coeffi-

y = 546.87 «77,

where: y = GNB/eapita in constant 1954 dollars,

x= year ~ 1960,

cient of determination. This fit vas:

Predicted values with above equation ind

© yearly

improvenents in GNP/capita at constant dollars of the

order 0.5 to 1.5% which is considered a:

low side.

yuate and on the

The predicted GXP per capita at constant dollars was

multiplied by the predicted population to obtain the

total predicted GNP at constant dollars.

Electrical Generation

The total electrical generation was correlated with

the total GNP and excellent correlations resulted.

1, Linear Correlation: Coeff. of determination 98%;

doubling,

Time 20 years

2. Power Correlation : Coeff. of determination 987;

doubling

?Time: 11 years

3. Log Correlation + Coeff. of determination 972;

doubling

Time: over 40 years

ut

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4. Exp. Correlation : Coeff. of determination 93%;

doubling.

Tine : 5 years

A statistical test indicated excellent correlations on

all of these.

OF all of the above correlations the log and exponential

correlations vere discarded because of poorer correlations relative to the Line

iF and pover correlations, and because

of the respective very slow and very fast grovth rates,

?The Linear and power regression analyses represent reason~

able selection projections.

Electric power generation doubled every five years fron

1960 to 1970, During the present decade it has doubled

every eight years. A doubling time of 11 years for the

1980-90 decade is therefore, not unreasonable, Doubling

times of the order of 20 years might be appropriate beyong

the year 2000, if the sane level of technology and habits

fare maintained. However, new technologies and new consuner

foods will probably impact beyond present expectations.

One example could be the developsent of urban electrical vehicles which require nightly battery charging. On the other hand, energy conservation measures will cancel these additional needs in part. The development of new technologies for producing electrical power from renewable sources might bring costs down and cause an incre demand. Therefore, the power fit represents an adequate

description of future electrical generation production.

?The power fit is given by, KHER gen = (0.001294)

cour)" 96

fat 1954 constant dollars.

x 10° vhore the unit for GXP ie million dollars

---Page Break---

Table 2.1.4 indicates che correlation data for popula tion, ONP and flectrical Energy. The

gures given for

electrical generation are comparable to PREPA forecasts,

but they tend co be low estinates. Powe

chnologies

prediction for the year 2000) ts 38,261 x 10° kane

generation which is comparable to our prediction of

42,910 x 10° same within 5x difference. ®

?The prediction of electrical energy generation for the

year 2020 show in Figure 2.1.4, using the above selected

relationship, is 89,120 million kw-hrs, which ig slightly

the current electrical energy generation.

?The Linear fir is given by KWR gen = -6709.03 + 5.21

(exp) x 10° where GxP in in a{lLions at 1954 constant

dollars. ?The last colum of Table 2.1.4 indicates the

kwhr prediction vith the linear correlation.

Energy planners and researchers must, therefore, think

of energy alternatives for Puerto Rico in a scale as large

as six times today's demand by the time when most energy

alternatives being researched today could be highly

competitive economically. Electrical energy is used around

the clock; hence, Large storage systems on direct solar

derived

"BY must be looked at in perspective.

(a) ?Long Range Sales Forecasting Study for the Puerto Rico Water

Resources Authority," Kevin A. Clenents and Robert de Mello, Pover

Technologies, Inc. ?Schenectady, N.Y. May, 1976,

(®) Ie should be mentioned that recent experience has shown lover growth rates in electrical energy demand than those used in this study, hovever, considering the long lead times necessary to place new units in operation (7 0 10 years) we have opted co use the vorst case in order to have a safe reference base.

---Page Break---

TABLE 2.14

GNE POPULATION AND ELECTRICAL PRODUCTION CORRELATION OATA

{Constant Prices /1954 Base)

See

: Power Fit Linear Fit

Pisce GNP/eapita Population GNP Electne Prod, eta tog.

Year Sieapita (thousands) (Smilions)?08KWehr nos ae

i

1882 69402826 1683.9 2870.7

1963, 73602473 1820.7 20345

1964 7680 2823 1936.9 3403.2

1965, 8170 2568 2090.2 3819.2

1986, e610 2603 22408 44298

1967 8920 2623, 2239.4 5080.7

1968, 9270. 2650 24553 57709

1969 10000? 2685 26840 68545

1970 107002711 2001.4 7539.5

vent 112002747 30758 85133,

1972 113902823 32159 102280

1973 11860 2910 34503117780

1974 1168.0 2991 349368 123209

1975 1130 3076 34287122089

1976, 11010 3167 3487.3 123498

1977 s160 3266 Bea 132904

1978 18003338 3837.5 137559

1979 1166.4" 3470 aoa7ae 145112

1990 12178" 3530" azgg.e 154296

1981 1246.52" 3650" 4549.7" 162072

1982 12041" 3720" aang.or 71975

1985 13109 3920" 51987 236840 20087.17

1990 13775 460" 5868.15 207340 23845 40

1995 14964 4520" 64925374830 2709653

2000 1499.4 4670" 6955.50 429100 2950724

2005 15378 5000 782740 4108.0 3407.17

2010 15825 5420 857.18 647480 ??37951.10

2015 y6240 5750 9298.00 765050 4191283

2020 16828 60701008320» 891700 5840.10

Planning Board Predictions.

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2.1.5 XW Denand Predictions and Additional Unit Requirenents

In order co convert the predicted kw-hr generation 4)

kw peak denands for the purposes of assessing additional

unit requirenents, a

sarly load factor of 77.6% will be used.

This is the average Ioad factor recently reported by PREPA.

System reserves in order to provide for scheduled maintenance

?and unscheduled multiple outages could vary between 50% and

75% for an isolated system such as PREPA and as high as 100%

for a syst

with special conditions such

units larger

than 10z of system peaks, The ratio of base load units to total system peak should be on the average comparable to the system load factor.

Tf 50% is used as the reserve margin for the PREPA system and 70% of system generating unite is used as @ criteria for installing base load units (as is the present condition) a rough indication of PREPA base load units required additions can be determined.

Table 2.1.5 i1ustrates che calculation of additional base load unite for the case of high energy demand scenario obtained through a power correlation. Table 2.1.5¢ Alustrates the calculation of additional base load unite for the case of moderate energy demand scenario obtained through & Linear correlation. The high energy scenario represents probably an upper limit of energy demand for which some planning attention should be given.

---Page Break---

TABLE 2.1.5 (a)

PRESENT BASE LOAD INSTALLED CAPACITY

IN THE PREPA SYSTEM (1979)

Unit Ident. Rated Cap.(MWhea. Total Cap.IMWW) Start-Up Date Retirement Date*

San Juan

ted 200 200 Retired

5 440 440 1956 1991

6 440 440 1957 i992

78 1000 200.0 1966 2001

2 100.0 100.0 1968 2003

10 1000 100.0 1969 2008

Pato Seco

? 825 225 1960 1995

2 825 825 1961 1996

a4 2160 4320 1970 2008

souco

1 440 440 1958 1993

2 440 400 1959 1998

3 e25 225 1962 1997

a 825 225 1963 1998

5 4100 4100 1972 2007

6 4100 4100 1973 2008

4500 900.0 1975 2010

otal Capacity (MW) 3058.0

+ A.35 year operating lite is assumed

---Page Break---

IMM 890? 5: 6/61 40 56 Ausedeo Yasue Peo! 869 FeMIoy 5 o0e-e cece vere tweak s0061 ne zie ozoe

oat vse caw te esztk soso si0e

raz (or Bizet eae ses'6 ener ioe

tice zoce rae eeu 656 s01¥9 sooz

Lio wot ¥e08 sr ico o1eee 0002

vezi aan e289 Lee sis cance S661

8201 ssi sees reo wes vecoe set

aie 8201 vee sees vere vaacz 864

MW suonippy mW deo VOL XM OL X su

Pateoipu sea

uu Bupus porrey peor aseg Purwed ones wr

JAG! pauinbay ?? pavinbou yee ~

stun wuonppy -

109 saNog) 889 puruing AB:0U3 YEH

SLNAW3YINDIY LINN GYOT asva MAN GNY G¥OT Nvad

(a sve reve

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oa vost tase p's eee soe ove

vise eu0Swe0'¥e so0e

uso ey cone o00e

sues 8600 661

wes woe tere 0661

vere eww Lew 051

7a

posted puede aet 10,

esvz nevi

Jewry) aSV9 ONVWAA 3LvH3GON

SANAWAYINDAY LIND GVO 3S¥8 TYNOLLIGAY ONY GvOT Avad

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2.2 GASOLINE CONSUMPTION PROJECTIONS

A simpie, preliminary projection will be made for gasoline and

eSesel consumption to approxinate total future energy requireneats.

iley transportation analyses being performed by Professor Jaro

Mayda under other related CEER studies will determine gasoline

consumption vith greater precieion.

Figure 2.2.1 illustrates both the historical and predicted Gasoline and diese! consumption in Puerto Rico. Gasoline consunp~ tion has been growing at the rate of 6.6% per year. The recent price increases in gasoline and the expected increases will reduce the growth rate con:

2 1/203% per year 8:

lerably, To be on the conservative side, a

}oline consumption increase is assumed for

she future, This is more appropriate than a regression analysis

of historical data becaus

?the transportation substructure is

changing rapidly to smaller cars amd to other more economical

nodes of transportation.

m6

---Page Break---

ast FIGURE 2.21

GASOLINE CONSUMPTION IN PR

AND PRELIMINARY PROJECTIONS

f

2s

\

w / GASOLINE PLUS DIESEL

= / PRELIM. PROJECTION

Ser / (2.5-3%/ yer)

Z| /

3 /

2,

i GASOLINE PLUS DIESEL

de casouine

|

---Page Break---

23

[PETROLEUM CONSUMPTION 18 INDUSTRY

A sinple analytic projection wilt be used for the projection

of petroleun consumption by the industrial sector in order to

predict total needs. Separate CEER studies being performed by

De. Levis smith wil

degree of confidence.

predict industrial needs with a higher

Approximately 15% of the oil consumption in Puerto Rico is

used for industrial purposes.

Aronatice petroleum derivatives account for 8.5%, nafta for 4.45%, and the balance is in tars and asphalts, waxes, and ciclohexane. During 1976, 26.3 million barreis of ofl were used directly by industry. This figure does not include the fuel used in generating electricity for industry which is accounted for in Section 2.1, The industrial needs for of vill be predicted at 5t per year growth starting froz the 1978 level.

?TOTAL OTL REQUIREMENTS

The eetinats

of the energy requiranents for Puerto Rico to ?the Year 2000 under the present socio-economic structure with Sone consideration for gasoline price elasticity and the absence of a strong RAD program for energy alternatives is show in Table 2.2.1

?The estinated oil cost indicated in Table 2.2.1 iy based on our lovest scenario of predicted ofl costs a9 discussed in Section 3.3.2, Our lowest scenario of predicted fuel ofl costs is based fon the predictions of PREPA consultant, Arthur D. Little.

---Page Break---

TABLE 2.2.1

ESTIMATES OF PUERTO RICO'S ENERGY REQUIREMENTS TO THE YEAR 2000

UNDER PRESENT SOCIO-ECONOMIC STRUCTURES WITH AN ABSENCE OF

STRONG R&D PROGRAMS ON ALTERNATE ENERGY SOURCES

?ilion Barrels of Oil imports For

Electrical Gasoline Industry Estimated Unit Total Cost

Year Energyl®) & Diese) g Other ©) Total Price S/BBLU® «S Milions)

197827 76 283847

1977230182 BT

1978 «8S EBD

197926017051 wat 18.70 1001

108007817988 7B 1203

m0 0 BS 7521917 az

m7 190 7B 2190 1708

39 198 308822 «25.00 2085,

36 2053208612885, 2458

33 21023368 99 32.70 2909

367014533 6.29 3390

279 1937089 80.28 3803

4220-25389 0368 = aa.72 4533

48 231 4091088 © 49.60 5306

4 236 4291139 55.00 6286

808280451199 58.75, 7084

a4 2854731252 62.75 7855

560-251-497 1308 «67.00 9295

sat 287 82.2 1707180 9796

620 280581828 78.50 r0024

650 845751489 BI. 12078

681-287 6041552 86.00 ss3a7

NS 4 ah 162395 14793

m1 2796681688) 16290

78 11756 ©1026 18016

Tour 3155 29

(a) Statistical Correations between population and GNP, and between GNP and

Electrical Energy Generation. Correlation 99%

(©) Gasoline Consumption growth projected conservatively between 2 1/2 ~ 2%

per year vs. 6.64 actual growth,

(2) Indust

neds projected at 5% per year growth.

(@) Fut oll prices escalation indicated is approximately 1980-85: 14.34/yeae

1985-90: 11% year; 1990-95: 6 8s/yesr and 1995-2000: 6% year.

---Page Break---

SECTION 3

COST ANALYSIS OF COMMERCIALLY AVAILABLE

ALTERNATIVES FOR ELECTRICAL ENERGY

PRODUCTION IN PUERTO RICO

---Page Break---

Section 3

(COSTS ANALYSIS OF COMMERCIALLY AVATLABLE ALTERNATIVES FOR ELECTRICAL

3.0

ENERGY PRODUCTION IN PUERTO RICO

Three alternatives vill be evs

juated in this section: coal,

nuclear, and oil fueled pover plants.

CENERAL COST CONSIDERATIONS

Im the cost analysis of electric power plante, three basic cost categories are considered: capital costs, fuel costs, and

operating and maintenance costs.

?The following are itens that have to be evaluated for elec~

tric power plant cost assesssents:

a) Investment Cost on per Unit Basis

The investment cost on © per unit basis (cost per Ke)

of an el

sctrie power plant is heavily dependent on the Size of the unit. The economies of scale dictate that the larger the size of the plant, the lover is the unit fed in dollars per Kw.

cost expr:

») Inflation

In an inflationary econosy the cost of equipment depends heavily on the time schedule proposed for commercial operation to begin at the plant project. Inflation factors must be considered. The time that elapses between the cost estimate preparation and the beginning

of construction will alter the cost estimates by the inflation factor during that period. During the construction period, inflation will affect costs on the un completed portion of the work.

TL

---Page Break---

©) Inter

During Construction

As funds aro invested and a2located during construc~

tion, interest on the investment for the period in

which the funds are not producing any commercial be~

Refit has to be considered. Construction schedules

must be defined.

4) Environnental Considerations

Mavironmental regulations governing air and water pol-

lution require high capital investment abatenent mea

?As an example, once through cooling systens

sight require long outfalls (with specially designed

diffusers) to discharge ware waters at the bottom of

?the ocean so as to enhance quick mixing and to maintain

the low temperature profiles that might be required

by water quality regulations. Forced mechanical draft

cooling towers might offer less intensive capital investment alterantive at higher operating cos!

?Ar quality regulations can make mandatory the instal

lation of costly wet scrubbers to renove $0, fron the

gaseous stack discharges of coal plants. The instal

ieion of static precipitators and fine combustion

controls for keeping particulate discharges to the at-

nosphere to ninimun must also be considered.

©) Site Related Considerations

Site location is another factor that affects the cost

of a power plant project considerably. Such factors

a8 terrain topography, site geology and seisnic consi-

derations, availability of adequate labor, proxinity

of electrical tranenigeion facilities, transportation

facilities such as marine port and ros

is, fresh water

ur

---Page Break---

Bal

3a

availability and similar factors can affect the cost

of the total project.

COAL PLANTS

General Considerations

Before considering the cost components of a coal fueled

electric generating plant in detail, several general principles

should be discussed in relation to the use of coal in Puerto

Rico. Since this is the first time that a coal plant is being

considered for Puerto Rico, there are no previous experiences or policies or cost records which could be extrapolated.

The type of coal to be used and the environmental restric
tions are subjects that need to be addressed. They will eub

tantially affect both the capital cost and the operating cost
of the plant.

Appendix A describes the various types of coals and the
nethods of coal cleaning or "beneficiation? together with the
cost implications for Puerto Rico.

As an island far avay from coal sources, Puerto Rico vill
be affected by coal mine problems Like strikes, and by land

?and marine transportation problems which could force frequent
changes from one type of coal to another. This will require a

boiler design capable of burning poor types of coal with high

sulfur contents.

?Transportation is the highest component of the cost of coal delivered to the plant site. This cost is assessed by weight. Hence, under normal conditions the transportation of clean or washed coals with minimum refuse, ash content and

sulfur represents a cost advantage since more Btu per 1b, will be contained in the cleaner coals at the sane transportation cost. Additional cost advantages accrued in the operation and

una

---Page Break---

maintenance components are discussed in Apnendix A.

?The problex of sludge aisposal on a densely populated is- land vith nearly 1000 persoas per square mile in 1980 and with Increases estinated to reach nearly 1,700 persons per square nile by 2020, makes the slucge disposal impact on the environ- ?nent @ matter of prime importance. This mandates that sludge disposal problems be ainimized if the coal alternative is to

be selected. This further points tovards the advantage of using clean or highly beneficiated coals. Sludges should be sinimi-zed, then stabilized by chenieal fixation and used for land fills

7

approach makes unrestricted fuel cost optimization proce-

Gores mandatory during the Lifetine of the plant, since they are the most significant ites of the total costs.

?The following general criteria vill be used to determine the cost of a coal plant in Puerto Rico:

4) Plant design should weet EPA 1976 New Source Perfor ?mance Standard (NSPS) as revised. Meat rejection eys~ tens should comply with latest revision of the Puerto

Rico Environmental Quality Board (QB) Water Pollution

Regulations.

b) Boilers have to be able to bum the poor type coals

which might be secured under energency conditions.

©) Clean coals, which have been optinally beneficiated

for lowest fuel cost and which will yield lower ash

and sulfur residues, will be the normal source of supply.

4) Boiler effluent sludges are to be chemically stabilized

for final disposal by trucking. This represents an

added operational cost, but has a lover investuent

cost and a lower environmental impact.

---Page Break---

In order to establish some meaningful investment cost re~

lations for considering all of the above factors, a general

?cost equation wilt be derived based on the following sumption

48) The basic cost vill include all direct costs such as
land and land rights, the physical plant consisting of

ties, boiler and turbine

plant equipment, electric plant equipment, and contin

structures and site faci

gencies. The basic cost will also include indirect
costs such as design and engineering, construction ma~

nagenent, construction facilities and equipment services.

b) ?The investment cost will include the installation of
SO, wet scrubbers and static precipitators for com
pliance with air quality regulations. The cost of

this type of equipment is dependent upon the characte-
istics of the coal. For coal typ
United States with high sulfur content and residual

from the astern

ash, larger volumes of material must be handled. This type of removal system will increase the cost. Lime stone scrubbing systens, as opposed to lime systems, must handle larger Liquid volumes and are costlier. ?The use of a Limestone scrubbing systen will be consi- dered for cost

Jluations, Adders or credits must
bbe used when considering different coal types. In this study, high sulfur coal will be
only under emergency or abnormal market conditions.

ssuned to be burned

©) Heat rejection will be to the atmosphere through wet,

air cooling tovers which use forced draft fans.

4) A ?nidétetown" coastal site will be assumed in which

there are no particular complex foundations or special

uns

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3.1.3

Seismic requirenents.

©) No coal handling facilities are included between the

nearby sea port and the plant boiler, nor are the

Port requirenents and coal storage costs considered

in the basic plant cost equation. All of these costs

WiLL be considered separately.

£) No investment costs for sludge disposal ponds are con~

sidered.

8) Basic cost (Co) wiil be based on early 1978 dollars. Escalation and interest during construction will be applied to the basic cost (Co).

4h) Only the cost of tho first unit of a two unit design will be considered. If a

jecond unit is built on a two unit construction schedule, the second unit can be assumed to cost between 85 and 96% of the first. lunit cost if the second unit lags the first by appro- ximately one year. This has been determined from Uoited Engineers and Constructors recent unpublished cost estimates ? ana epai-ps-s66-sp 4),

Interest During Construction ané Inflation Formula

onstruction and Inflation Forma

A complete derivation of the formula is presented in Ap-

pendix B. In treating inflation and interest during construe- tion, the following procedures vill be used

Figure 3.1.3 represents the flow of cash outlays for the

project. Y, represents the number of years between the date

of the present estimate, carly 1978, and the start of construc~

tion. Y) is the actual construction time. The abscissa of

the curve is expressed in per unit of construction time and

the ordinate in per unit of cumulative investuent during

m6

---Page Break---

Figure 3.1.3

Interest Ouring Construction ond Inflorion Formulas

7

EXPENDITURES ©

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Les

("sruoy ?construction

ciaeinen um "

ene [unl dane 5

Simple inflotion on unspent dollars during AX time at x,

rUn2) AKL re 1

Tote! simple Intletion during construction »L¥2 [l1-B)d x

ona [r-#) 4x +I-0

COMBINED INTEREST DURING CONSTR, AND INFLATION

COMPOUNDED = brig FOCI Hage) aC

m7

---Page Break---

construction. The area under the curve

is representative

of the construction time fraction which is used to calculate

the accrued interest during construction, The area above the

curve is equal to Ina (since the curve has been norsalized),

and is representative of the time fraction during construction

in which the unspent money is subject to inflation,

Interest during construction can be expressed as follows:

48

Tyg = (tig 92

Inflation between the time of the estimate and the com

pletion of the project is then:

?The compounded interest rats

for coubined inflationary

ang interest during construction charges can be

accounted for in a cost equation as follows:

Yella, ay,

iY 2 2

(Keto). Tye

where:

total cost in $/Kw

Co = basic cost in $/Kw for the base year (1978)

Y= years elapsed between base year (1978) and begin-

ring of construction

Yy = construction time in years

Ig = 1+ ig, where ig is the average yearly inflation

Tye 7 14 iggy where gg is the average interest rave

during construction

2 area under the normalized cumulative cash flow

curve during construction

K = other costs which include, site variations from

?middleton? site, port, special coal handling

ura

---Page Break---

facilities, coal storage and other particular site

related costs evaluated at base year (1978).

?The $ type curve of cumulative cash flow must be defined.

For the type of curve defined in Wash 1345 (7)

is approximately 422. Various type $ cummulative cash flow

the value of ?a?

curves are given by Budvani ©), wo extrene fluctuation can

be expected in the values of "a." In the case study of the

coal plant for Puerto Rico to begin operation in 1985, the short

construction period that has been proposed gives an $ curve

with a value of "a" of approximately 0.48, For a straight Line

approxination of cumulative costs, ?al? is 0.5.

Evaluation of Basic Capital Cost, Co

Plant with FCD System

co will depend upon the size of the plant and will have

the conditions already stated as a basis for the coal plant

cost equation.

wasn 1345

gives the cost of @ 1300 Hye coal plant under

various assumptions using the year 1974 as basie, The estimate,

?excluding escalation and interest during construction for a

plant with $0, wet scrubbers, was inflated at 8% per year to

correspond to 1978 prices. A cost of $410/net ¥w was obtained

for a first unit plant based upon the criteria established here.

Five dollars per kw (1974 prices) were credited to the natural

evaporation tover to allow for forced mechanical draft cooling.

A 5.9% auxiliary power wi

estinate as determined from Hash 1345 w

assumed (Figure 3.1.4), The cost

found to be too low

when coupared to other recent estimates. This cost estimate

does not comply with the 1976 EPA New Source Performance Stan-

dards (NSPS). Therefore, this data point vas disregarded.

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Ay20d09 29MM 55019 WOId

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S4U0/d 48M0d pai[4 1009

41120009 HoMob2W $8019 Jo UoHOUNY D sD JeMog saJ40))1xnNY

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ENERGY REQUIRED BY AUXILIARIES

---Page Break---

Recent unpublished studies performed by United Eagin-

?cers and Constructors (UEC) estinate in great detail the

?costs of 1300 ty and 850 My units, Based upon the assurp=

fons of our cost equation, the basic coats for a first

unit including 10% contingency and BE escalation for 1 1/2

Years (aid 1976 to 1978) vere determined to be $524/iu for

19 1252 thee net (1309 Hw gross) coal plant, and $597/kw for

12 79% we net (B54 Mv gross) coal plant. The detailed cost

feetinates are presented in Appendix C.

De Rienzo presents 2 recent unit cost estimate for a

two-unit station for 4 1150 Wwe plant equivalent to $495/ky. 09

Ye i assued chat these are gross Kw, An additional 62

should be added to the unit cost to correct At to the one=

unit basis. By correcting De Riento"s estimate to agret

with our basic assumptions, a cot of $526 per net hy is

calculated (see Appendix ©)

Ksopp, Hansen and Destefanis estinate 4 cost of $800/kw for 4 20 Wwe coal plant based on 1976 costs. this es inate is used directly as given (see Appendix ©).

?The most accurate cost analysis has been prepared for

PREPA by Architect Engineer Consultants for a 450 $8 gr a2)

coat plane. (2) pRepa cost estimates exclude the cost of

the turbine because the sane vas already purchased and is {in storage at the Aguirre site. Twenty five million detiars ?was added to the PREPA estimate for this item. This amount as determined by escalating the original cost. Tn addi~ tion, twelve million dollars vas added for the FGD aystem to allow for the burning of high sulfur content type coal. For the 450 Yi PREPA cos! plant 7.9% auxiliary power is estimated (including $0, vet scrubbers and aechanécal draft fans for wot cooling tovers). See Figure 3.1.4, Folloving

rm

---Page Break---

tthe UEC format, the PREPA cost estimate is adjusted to $282.18 millions (1978 dollars). See Appendix ¢ - First PREPA estimate.

A second estinate vas prepared following the PREPA consultant's format. Separate adjustments were made for the turbine cost and added FOD aysten. The total cost estimate was $281 millions vhich agreed very closely with the first estimate of $282.18 millions.

If §2 million ie added for land rights, the total estimated cost is $283 millions. The total unit capital investment cost is then $683 per net plant Ky output.

Publication ORAU/I EA (M) 76-3 was examined for data fon capital charges of 2 1000 Mye coal plant.?!3) his estimate vas made prior to the 1976 NSPS, and so the data point was disregard:

?The Electric Power Research Institute (EPRI) Special

Report PS-866-SR (June 1978) vas also examined. The lovest estimated cost for a 1000 MM net coal plant is $550/Kw on a twouunit basis, which becomes $573/kw by using a 1/0.96 factor for 2 one-unit plant. (See Appendix ¢).

A cumnary of the cost data for capital investment of coal plants is presented in Table 3.1.4.1 and Figure 3.1.4.1.

mrel2

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te 3.

CAPITAL INVESTMENT FOR COAL. PLANTS

BASED ON COST ASSUMPTION OF COST EQUATION

(1 unie ~ 1978 coste - $0, removal

wet cooling tovér)

Net 164 Cost/Not Kw Main Reference

20 800 a

as 683 a

796 397 9

11000 573 uw

1150 526 10

haz 534 9

A curve fit was performed using the data of Table 3.1.4.1, An exponential regression statistical fit gave 4 value of determination coefficient of 99%. The cost ?equation is,

c, = 795.95 « ?00003428

Where:

c, + base cost in $/net Ku, 1978 dollars

Mi = plant size in megauates

?The total capital investment cost ¢ for a coal plant is, therefore, given by the relation:

c= [x + 795,955 ~2-c00240m | [rf t or, tye 2] ©

Where K is the sum of special adders for a particular site

and utility organization.

This equation is applicable to any coal plant for sizes

ranging between 20 My and 1300 My, which practically covers

tthe entire range of values. The equation is also good for

any future date regardless of the inflation rate and interest

charges during construction.

---Page Break---

FIG.3.1.41

Coal Plent Basic Cost Investment Equation with FGD

9007

i

@

10

a

300]

1978-$7KW Investment Cost, co

»

00k

System. Least Square Fit

Co* 795.75 e~0.000341005 NW

7240.99

REFERENCES

United Engineers and Constructors Recent Estimotes Personal

Communication = Feb. 1979

Gibbs ond HILI- Pov! de Rienzo Neplo Me

10 Moreh 1978

ASME Conterence-1979 Destefanis et ol.

PRWRA-Jose A. Marina Personal Comm. Feb. 1979

EPRI-PS~ 666 -SR- June 1978

00 190 oo 700 7305 7200 7700

Megawatts

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?POD System Investment Costs

The investment costs of the FGD System have been in~

cluded in the evaluation of Co and in the estinates given

in Appendix C. A wide variation for the investment costs

in FOD systems is reported in the Literature. In Appendix

© these costs are reported for the case of United Engineers and Constructors and for the case of the EPRI @echtel Study) ,

For the UESC report the invest

ent costs for FGD system

ranges betwoen $73/net kx for the 1232 Mi gross unit to

$86/net Kw for the 854 Mwe (gross) units escalated to 1978.

?The EPRI report shows cost ranges from $85 to $155 per Kw.

?The 1975 report ?Detailed Cost Estimates for Advanced

Effluent Desulfurization Processes" ?>) describes costs

escalated to 1978 at 82/year as follows:

200 Mv units 879/ke

500 Mv units $54,8-61/K9

1000 Mi units 8465.7/Re

?These latter costs are too low when compared to recent

ESC and EPRI estimates

The recent UESC estimates are detailed and are based

fon the present state of the art. These estimates for F6D

aysten investment coste in $/kw between the 1232 Mie and

856 Mile plants vary inversely with the .45 power of the

capacity ratio.

If the same rule is applied to 2 450 Me gross unit,

the added investment cost of the FGD system is $114.00 per

Ku. This value falls well within the values quoted by

EPRI for 1000 Mwe plants (85-155 $/kw).

For the purpose of adjusting coal plant costs for com

parison with other alternative energy sources, the following

mis

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eavg So7d03) 9p osyaseueed

Tram

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[ensov 0-s1 08

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30N31U34x3 NolLsNdOMd

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dn- aw2s-NolivAounY

?uNaMdOT3430

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(312s 907110061) m/s AvuuW/aTNGON

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3.15

investment costs for FGD systens will be assumed:

TABLE 3.14.2

INVESTMENT COSTS FOR PGD SYSTEMS

1978 CURRENT DOLLARS

Size (Gros POD cost $/Net Kw

450 Me 100

856 we 35

1232 5

It should be noted that the

are included vith~

in the evaluation of the cost equation Co.

Evaluation of K-Plant Cost Adders

?This portion of the cost equation is not

dependent upon plant size

tions included in the evaluation of the basic cost

0.

strongly,

the other factors and assump-

lation,

?The following items are included in the value of K.

K = Plant cost Adder:

a) Special facilities euch as roads, sea-port éredg~
ing requirements, coal handling equipment, fresh
water supply, ete.

1») Flectrical spur lines or cables to tie the pover
plant to the power system switchyard, including
tthe corresponding H. V. terminal.

©) Cost of a storage pond for effluent disposal.

4) Taxes. This depends on the locality and the con
ditions, and on private ve. public utility organi

zations.

fe) Other miscellaneous costs not specifically mentio-

ned.

m6

---Page Break---

The value of K cannot be computed unless a particular

site, locality and utility organization have been identi~

fied, In the final economic comparison the sites of Aguirre

and RineGn are identified for assessment of the value of X

within the PREPA system.

Gost Adders for the Specific Site at Rincéa

Since our interest is to compare cost alternatives,

those adders which vill add the same approximate dollar vs

ve to each plant can be disregarded.

K, Special Facilities - Port, Dredging, and Coal Handling

In the 1974 study of various sites for an of1 su-

Perport facility in Puerto Rico Van Houten Associates

ade soue preliminary estimates of marine facilities

for Rincin.® Figure 3.1.6 is taken from the Van

Nouten report. The size of the marine transportation

vessel was the subject of cost analysis optimization.

?The minimm total cost results in vessels of about

85,000 - 90,000 dead weight tons (DWT). The analysis

is based upon the requirements of two 450 MM coal fired

?units using 1.008 million tons of coal per year. Un

fortunately the values of the curve on Figure 3.1.6

cannot be escalated to 1978 because the various compo

nents have different escalation rates. PREPA consul~

tants have recently estimated the cost of a seaport

facility at Rincén at $84 million dollars.

?These vill be the same for al1 alternatives at the

same site and s0 they will not be considered.

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Figure 3.1-6

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16 20 76 %o 30 706 ?120140

SIZE OF MAX, VESSEL UTILIZED (MDWT)

RINCON STATION

MARINE FACILITIES

OPTIMUN COAL CARRIER SIZE

(ax. thruput rate = 3.6 x 108 Loog Tone/¥e.)

sey 1976

Van Wooten Atsoctates, Ines

mi8

---Page Break---

Haste Disposal System

The Rincn Site does not have sufficient space for

Sisposition of the PCD sludges, which instead sust be

treated and trucked avay. The Authority owns only 143

acres of land in Punta Higuera; therefore land must

be acquired even for locating such facilities as the

electrical switchyard. The topography is very hilly

?and no nearby land is suitable for sludge disposal.

A simple calculation for the disposal of the sludge

from one 450 My unit indicates that a 583 acre pond

20 fe. deep will be required for all the solidified

sludges during the plant's lifetime of 35 years. This

calevlation is obtained by assuming a 2.7% sulfur con

tent, an approximately 1 Kw HR generation per 1b. of

coal, a 75% capacity factor, and a line/Linestone

scrubbing system which generates 10 Ibs. of sludges

with a density of 55 ibs. per cu. ft. for every pound

07) 4 sludge stabilizing facility

located at the electric plant site vill add approxima

rely $15.00 per gross kw capacity or $6,750,000 total

in 1978 dottars, (18 195 20, 215 22). are srudge

stabilizing plant, which is needed to change the sludge

of sulfur remove

characteristics from thixetropic (quick-sand) into a

hard material with acceptable structural Toad bearing

properties for land fi11 (2 tons per square foot),

includes miscellaneous equipment euch as a: pump house,

?ix tanks, silos for chemicals, flush water tanks,

transport pipes, ete. Various proprietary processes

Tech (IV Conver-

sion System) and Chenfix (Carborundum) could be employed.

such as Synearth (Dravo Corp.), Po2~¢

nrg

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The alternative to the stabilising plant will be the direct ponding of the untreated sludges. The land required

for sludge disposal during the life of the plant will have

to be purchased as a whole at the beginning of the project

Other costs

could be defrayed on a yearly basis as the operation requires.

because of environmental inpact consideration:

However, assuming that escalation offsets the interest of

Profits of a deferred investment, the following rough esti-

fate can be made for the direct sludge puaping alternative:

8) six hundred acres at $4000/per acre $2,400,000

>) tspounding at $703/acre~fe*)

(575) (20) (703) 8,084,500

©) Environmental control:

clay or synthetic Lining of pond area

and drain control at $30,000/acre) 8,000,000

$28,484,500

?The impounding the untreated sludges alternative vill un-

doubtedly receive serious opposition because of environmental

factors and land. use considerations. The capital investment is at least four times more expensive than it is for the alternative of sludge fixation. It has, hovever, lover operating costs. Whether the lover operating costs are enough to offset the higher investment charges requires

ore detail

analysis then this work can provide. We feel ?that such study will have to be complete enough to include

Cost estimate wade by VESC or a 1250 Mwe plant and adjusted by Giscounting land costs at $300 per acre in a U.S. wasteland area.

(b) Average estimate from costs of asphalted surfaces and roof imper-meabilization costs in Puerto Rico.

---Page Break---

the environmental impact of the unfixed sludge disposal which this study has Created as simply as possible be-

cause of the assumption that it is not a viable alterna~

tive for Puerto Rico.

In summary, additional cost due to f.

815/kw, oF $6,750,000

K, Taxes, Permits and Fees

Contributions in Liew of taxes are paid by PREPA. ALL

alternatives are affected equally, and since the differen

tial is zero, this factor will be omitted from the study.

Summary of K cost adders for Rincén:

K, pore '84,000,000.00

K, elect. facilities ~

K, waste disposal plant 6,750,000.00

K, taxes

?Tora. 390,750,000.00

3.1.7 Cost Adders for the Specific Site at Aguirre

K, A detailed cost estinate for port facilities at Aguirre

hhas been made by PREPA Consultants. They include navigs

tion channels over two miles long to reach beyond existing

(a2) $9246,000,000.00

coral reefs

K, electrical facilities -

waste disposal system same

Rinen Site (see section 3.1.6) 6,750,000.00

taxes, permits, fees, etc.

$153, 750,000.05

?The site of Aguirre will be disregarded in the economic

evaluations.

m2

---Page Break---

3.1.8.1

Fixed charges Considerations

General

Electric power plants in Puerto Rico are owed by a go-

vernaent public corporation. As such, no property taxes,

corporate income taxes, charter licensing taxes, etc. exist.

?The form of evaluating the fixed annual charges is therefore,

greatly simplified. Fixed annual

larges consi

1¢ principally

of interest on bond issues, amortization on a sinking fund type of account, plus @ small fixed percentage to cover pro- erty insurance (property insurance ie a function of the ca~ pital investment). In addition, an amount to cover plant depreciation is considered. The consideration of plant de- Preciation in the economic comparison of alternatives has been a subject of discussion for many years, Arguments have been presented both in favor of and against the inclusion of ?4 plant depreciation factor in the economic comparison of alternatives.

PREPA Trust Indenture requires that the electricity rates cover the cost of interest plus anortization, plus a straight ine depreciation of investment. This helps to build up ca- pital in order to provide an adequate safety margin to pay

the debe. Such a sai

ey margin, known either ee "financial coverage? of the outstanding "debe" or as simply "coverage", is caleulated by dividing the net revenues (revenues less all operating expenss

the committed periodical (or yearly) paynents of the debe

(Bebe Service). The ratio should be at least a minimum of

1.5 which is typical with most public corporations. The grea~

) in a period of, say, one year, by

ter the coverage or safety margin, the better the financial

position of the corporation resulting in better market con-

ditions and lover interest rates for future bond issues

mr-22

---Page Break---

3.1.8.2

?This is the reason for the inclusion of a depreciation factor

in the evaluation of econonic alternatives,

The other point of view ie that the addition of @ plant depreciation factor should be considered uace the lowest cost alternative to the public has been determined.

In making the economic comparison of alternatives, one should decide upon the alternative that represents the lowest cash outlay or cost to the consumers (including environmental costs). The addition of the depreciation factor to the anor~ tization of the investment is equivalent to a double type depreciation which builds up an equity or "gain" for the public corporation. If this is included in the economic comparison, it can lead to the selection of an alternative which does not represent the lowest cost te the consumers even though it could be the best equity build-up for the corporation. The economic comparison of alternatives should therefore exclude the depreciation factor.

once the Low

#E cost alternative is selected, then the depreciation factor should be considered in making a cash flow study of money and financial requirements of the corporation to determine the "coverage." Other governmental policies and financial considerations should then be accounted for in the analyss

Capacity Factor

The selection of @ plant capacity factor for use in cost

comparison of power studies has always been a controversial

point. In computer prograns of generation expansion of power

systems, capacity factors are not set a priori. The scheduled

outage rate for maintenance purposes (4-6 weeks per year) and

+ and the modifications should be made as necessary.

the statistically determined forced outage rate from historical

---Page Break---

records indirectly fix the upper Limit of the capacity factor.

?The generating units have to compete with each other in an

?economic incremental dispatch program determined by a series

of coordination equations which winimize the total operating

costs. The system expansion alternative vhich produces the

total mininun cost is the preferred alternative from an eco-

nomical point of view. The unite having the lowest incremental costs will be more fully loaded and will exhibit the highest capacity factors, The actual operation of a power syste follows the sane principle of economic dispatch. Hence, capacity factors for coal power utility records are strongly biased to 4 lower value by the presence of lover incremental costs units

such as nuclear and hydro units.

In order to take this into account, Komanoff has defined capacity performance (CP) as that which would have been experienced had the plants in question been fully base-loaded. (2°) Komanoff's results have been highly controversial.

Hohenener, Goble and Fovler prosent interesting results using the Konanoff statistical analysis, (24> 25)

It is an observed fact that the forced outage rate of the generating units increases with size and complexity. The expectation of capacity factor for a coal plant during the 1ifetine of the plant should average 75% irrespective of the

plant size. Yor the purpose of developing baseline costs in

Puerto Rico of conmercially available alternatives for compa~

ison with new alternatives requiring R6D efforts, this simple

assumption is adequate.

Station performances are also reported in "20th Steam

Station Cost Survey" in Electrical World, Nov. 15, 1977. (26)

Edison Electric Institute (EET) has probably the most

---Page Break---

extensive compilation on Capacity Factors (CF), Availa~

bility Factor (AF), Equivalent Availability (EA), and

Forced Outage Rate (FOR) for coal and nuclear plants of

400 wi and targer. (27) 4 752 aver

ge Lifetime capacity

factor for coal plants is considered reasonable, Never theless, parametric studies could be performed with ca:

pacity factors if necessary.

3.1.8.3 Fixed charge Rate

Fixed charge rates to be considered consist of the

interest plus amortization in sinking fund, or the capi-

recovery factor plus insurance ag discussed before.*

Let F.C. = ORF + Ins

The annual cost in mills per kwhr is then

0) Oo) __.6.) x 1000 = (eo) F.C.) mills/kwhe

(6160 x HH CF) CFG. Te0)

where:

C= capital investment cost $/kw of net plant capacity

C.F. = capacity factor

F.C, = fixed charge rate

Substituting in the previous equation for the value of

©, the investeent charges in mills/kw-br (plant with PCD

system) ie given by: Total Investment Charge =

(295,950 ?00032 4 gy 161 # Clow? 9,2 Be, eitte/teahe

TET

?T~EPRI-PS-BOO-SH Includes Ih the fixed charge rate an allovance for

what is called Retirenent Dispersion to take into account the ste

tistics of unit retirement. An allowance for a retirement disper-

sion of 0.51% is calculated for a 35 year lifetime. This concept

has not yet been fully adopted by the industry and will not be

considered here. (Ref. 14).

125

---Page Break---

3.84

Example of Tavestnent Charges Calculation of a 450 Mi Gr

Assumed Interest Rate = 9Z/Yr.

Plant Life = 35 years

Capital Recovery Factor (CRF) = 0.094636

9.004

Fixed Charge Rate (CF) = 0.098636

?Assumed Capacity Factor = 75%

y = 1 year

%» = 6 years

co = 683 S/kue

K = $90,750,000.00 = 219.2 $/kw

ere eto. oo

= 1.08

lee = 1.09

a = 0.48 (see end of section 3.1.3)

= 4a2

ex, = 2.88

(2,08)? « 1,373

(2,09)?°88 = 1,282

10985 Capital Investment Cost:

© = (683 + 219.2)(1.373)(1.282) = §1588.06/k0

Cost in mills/kwhr (1985) = (1588.04) (0.098636)

Oe

Fixed Charges = 23.8 mille/kwhe

?¥ The corresponding Figure Tor net capacity is $691/KW which only adds

0.25 mills to the levelized cost.

---Page Break---

Goal Fuel Costs for Puerto Rico

Generad

The vulnerability of fuel prices to international ac~

tions, such as those of the OPEC cartel, is an established fact. Prices of competitive fuels follow the OPEC oil pri-

ces although not necessarily at the same rate, This factor Lends ?0 change the prices of competitive fuels at a faster

(28)

rate than normal. Coal prices and those of other fuels

rose dramatically in late 1973 and early 1974.

Prices for coal purchased under long term contracts are spore stable, but are not necessarily lower than spot purchase prices, The greater reliability of supply vith long-term contracts is the most important consideration when comparing these contracts with spot market purchases which are influ- ?enced by short-term market variations.

Coal prices will also respond to changes in production ?and transportation costs. Because of the high transportation cost, coal has been until the present time a regional type of fuel.

OPEC action has caused coal to be considered as a non~regional type of fuel sooner than it would have otherwise been.

?The mine-novth coal prices will depend upon the inflation rates of materials, equipment, labor, and operation

and maintenance costs. This inflation rate has been estimated at 8% per year in other parts of this study, and it

is logical to assume that mine-mouth coal costs vill increase ?at the same rate.

Transportation costs should increase at a lover rate

than materials and labor costs because this iten is highly

---Page Break---

capital intensive. The investment has already been made and 80 the escalation does not affect the transportation equip~ ment investeent. A six percent (62) inflation rate on trans~ portation charges should be wore accurate, (29)

The indicated

alation rates will be applied in this study to domestic types of coal as well as to foreign types. However, prices from foreign sources could be lover.

Shipment of domestic coals to Puerto Rico must be done in vessels under United States flag, but shipment from fo~ reign countries can be done in foreign vessels. It is a

fact that transportation costs in United States vessels are about the highest in the world. Since transportation costs are the biggest component of the total coal cost, it is a Teal possibility that foreign sources would compete very fa~ vorably with United States sources, provided no federal taxes are levied on the foreign coals to protect donestic producers. Any long term contract with foreign sources should be entered into vith this in mind.

Figure A-l in Appendix A presents the coal fields in the Continental U. S. A, Coal fields are divided into four re- Bions according to the total reserves and the low sulfur coal Fenerves. Appendix A also indicates the distribution of coal reserves in a bar chart.

Coal costs data in the ORNL~4995 Study mentioned earlier are reported up to 1972, but thie data is not reliable for future projections, Nevertheless, it is reasonable to as sume that Puerto Rico will probably obtain the lowest coal costs found in the United States market from the area of West Virginia and Alabana. This area offers the shortest trans~ portation routes

to Puerto Rico. The current low price won't

necessarily resain so since special market conditions can

me28

---Page Break---

3.1.9.18

change.

West Virginia and Alabama

they could be in high demand.

(is are excellent and

Anvestigations from various suppliers to ass

coal costs to Puerto Rico, (+ 22) tape 3.1.9.1¢a) 4

PREPA Consultants have performed recent detai

sumary of these investigations.

TABLE 3.1.9.10

ei

1977 DELIVERED CORL PRICES TO P.R,

Short Ton)

W. Virginia Wyoming I1Vinois Alabama Colombia South Africa

£08 wine

sr 26.31 6.70 22.28 29.00 oe

Ratt Transp.

s/t 9.18 9.65 2.75 4.98 oe

River Transp.

st _ 6.28 4,50 -

cean Transo,

si 8.45 8.96 10.78 9.89 ?

TOTAL $/T 43.98 31.45 40.31 43.87 29.27

wwaTUsT 26.00 17.00 22.00 26.00 21.68

sper 1.69 1.85 1.83 1.69 1.35

?Prices not considred reliable

m2

---Page Break---

3.1,9.1b Burns and Roe Coal Price

Budwani® from Burns and Roe indicates an average hhigh value of coal burned by U.S. utilities in 1977 as $1.35 per MUBTU. When the ocean transportation costs detersined for the lowes fuel costs in Table 3.1.9.1a are added, coal fuel prices for Puerto Rico will be $1.675 per MBTU for West Virginia and $1.73 per MMBTU for Alabama. Budwani's figures agree very closely with Table 3.1.9.1a.

FIGURE 3.1.9.1

AVERAGE COST OF COAL BURNED BY ELECTRIC

VTILITTES DURING 1972-77 PERIOD

Cents /milton Btu of fu

Volue conta

ooo

?The low values are for mine-mouth plants, The cal~

culated average values are derived from average costs for 30

utilities in all parts of the United States.

---Page Break---

Recent cost estimates by VESC for high sulfur

?and low sulfur coal indicate che following costs:

TABLE 3.1.9.16

OULY 1976 DELIVERED FUEL COST TO A U.S. MIDDLE-TOWt SITE

(wet)

Western Low Sulfur Eastern Hi Sulfur

Combet County, Hyoning Saint? Clair County, T11inots

Mine ($/T) 6.43 19.00

Transp. (8/7) 20.43 3.19,

TOTAL (8/7) 26.85 28.19

weTu/T 16.33 22.05

?S/MuBTU 1.65 1,28

?A comparison of the miné costs between Table

9.1a and 3.1.9.1¢ indicates an escalation of 4.2%

for the Wyoming coal between July 1976 and 1977, and

17.2% escalation for the 11inois coal price. There is

?no strong discrepancy betveen Tables 3.1.9.18 and

3.1.9.1¢ coal mine costs

31.9,1d Summary of Coal Prices

?The above analysis shows that the average price

(1977 ees

fluctuate between $1.35 - 1.65/M@TU, excluding the over

seas transportation costs. Indicated costs for South

rence base) within the United States can

m3

---Page Break---

African and Colombian coais look rather low even after the

overseas transportation costs are added. A serious econo-

?mic analysis can not be based upon foreign costs which

could change unexpectedly because they do not have a real

Pricing basis. It will therefore, be nore appropriate

to base economic comparisons on domestic coals. Nonethe-

less, any real advantage offered from purchasing low cost

foreign coals should be taken into consideration.

Te seems that coal costs on the basis of 1.70

er MIBTU (1977 reference base) can be possible for

Puerto Rico. Escalation of this cost will be made at

7 A/4% per year. This has been determined by weighing

?the escalation of the transportation cost conponent at

6% and of the mine component at 8% for the West Virginia

hd Alabama coals.

TABLE 3.1,9.18

COAL Cost AssuMPrroxs

(1977 ?nase ~ §1.70/003

Escalation 5 7 1/4t/year

Coat Type + Alabama and West Virginia

1978 Base 2 $1.82/em6Tu

---Page Break---

9.2 Levelized Fuel Coste in Mille per Kwbhe

After the power plant begins comercial oper:

tions, the capital investment cost component is not

subject to inflation since it has already been spent and

the interest on borrowed capital is fixed. However,

fvel costs will continue to suffer from inflation. In

order to add the capital charge cost component to the

fuel cost component, the two have to be on the sane

basis, A levelized fuel cost during the plant Life

should then be considered\??**He analysis for caleulat~

ing the Levelized fuel cost is derived in Appendix F.

?The levelizing factor L can be expressed as,

GQtor-r | tae

ne Gem

rare a+

where:

n= number of years (usually plant Life tine) for

levelization

A * cost of money or discount rate, usually equal to

tthe interest paid on bonds for public corporations.

r= effective discount rate corrected for total infla-

tion, such that r = i-U where u is the total

Y¥u average yearly intl

tion rate of the

product.

?The Levelized fuel cost in mills per kwhr can then be

expressed as follows

y a saea?

Pe) (HR) (1 + 1+m"-1 | say)

1000 9 Se. aa

Pe ¥ coal price in dollars per M@TU for base year, 1978

HR = plant heat rate in BTU/kuhr

Y + number of years between base year of estinate and

beginning of comercial operation.

---Page Break---

3.1.9.3 Example Calculation of Fuel Cost for PREPA 450 sv Plan

For the specific case of the PREPA 450 MW plant ve have:

Value of Pe:

@

3)

1978 base year fuel cost at $1.82 per MTU deternined in Section 3.1.9.4

carrying charges on coal stock pile 3 month stock

equivalent to 1/4 ton in stock per ton burned at

10% carrying charges equals 1/4 (S1.82/M#87U) (0.10)

or 0.0655 s/eorv.

Pe

HR

?e

FL

= $1.87/@re

= 10,000 Btu/kwhe

Heat rate of a 450,000 RW Plant operating at

73% Loas

factor (12)

= 7.25% (escalation between 1978 and 1985,

X'per year)

= 35

+ 9 (PREPA cost of money)

= 5% (eotalave. yearly escalation rate

1985 = 2020).

= 0.038095, determined from the relationship

ofr, i, u

= 7 years (1985-1978).

= @.87).10,000) (1.0725)? . (1,038095)35 = 1

7,000 (0.638095) (1.038095) 35

+ (0.09) (1,09)35

eos

= @DG.81) = 56.11 wilte/eshe

meu

---Page Break---

3.119

erating and Maintenance Costs for Coal Plant with

oD Syston

No experience exists in Puerto Rico with the operation

and maintenance of coal fired or large commercial nuclear

plants, therefore, it is not possible to extrapolate

hi

orieal figures, for the Operating and Maintenance

costs (0 & M).

8

?The evaluation of O & M costs in this study is b:

reainly in the ORNL publication ?A Procedure for Estimating Nonfuel Operation and Maintenance Costs for Large Stean~ Electric Pover Plants"? and on personal communications with United Engineers and Constructors,

?The total 0 & M costs are composed of staff, fixed and variable maintenance, fixed and variable supplies and

?expenses, insurance and fees, and administrative and

general expenses.

?The procedure is based on determining First the total

plant manpover requirements from normal experience in

other similar plants, Once the average cost per enployee

for a particular utility is know, the total staff cost can be

determined. This is usually the largest single cost iten.

Fixed and variable maintenance costs are correlated with the staff cost.

Fixed and variable supplies and expenses are a function

of plant capacity and kwhr generation, respectively.

mII-35

---Page Break---

3.10.1

3.1.10.2

Insurance and fees are a function of plant investment.

Administrative and general expenses are correlated with

total fixed costs,

Staff cost

?The yearly 0 & M cost of the plant staff is determined

from the following relationship:

TSC = Total Staff Cost = Mx Pm (1 +e!

where:

M_ = number of regular exployees at the plant (excluding

transitory labor)

Pa = average annual cost per employee at the tine of the

estimate (1978 base year). This includes ali costs

such as salary, fringe benefits, overtime pay, ee

= average annual escalation rate for the utility,

x/100.

Y + nusber of years between base year (1978) and

beginning of comercial operation of the plant.

Tables 3,1.10.1 and 3.1.10.1a present the manpower requi-

renente.32

Fixed and,

ble Maineenan

a) Fixed Maintenance

?The ORL correlation studies}? indicate that

approximately 75% of the total maintenance material

cost for coal fired plant can be considered the fixed

portion of this item, Approximately 45% of the total

staff cost {s the annual total maintenance matetial

---Page Break---

TABLE 3.1.101

STAFF REQUIREMENT FOR COAL-FIRED PLANTS

WITH FGD SYSTEMS.

400-700 MWie) Unit___707-1300 MWe) Unie

Units per Ste Unite per Site

72 3 4 F234

a, ie ee a Oe

Plant manager's office

Manager Por tr td dG

Assistant 1203 4 1 2 3 4

Environmental control Po rr a 4G

Public relations i

Training i

Safety rs

?Administrative services 3 5 6 ee

Heath services yor a 2 ta 4 tg

Security 22 82 4 27 7 9

Subtotal 7 PR BH T B BF

Operations

Supervision (excluding shift) 3 «3S Bg

Shite 4 8 60 6545 8g

Fue! and limestone handling 12,=«12,=12BSCdND?Ss1Ds1B

Woste systems 13 90 45 601530450

Subtotal 7% 8% 1% We 3 95 ia2 ina

Maintenance

8 8 wm 2 8 1 2

9 115 135155 120 140 160

Peak maintenance annualized 3366-99192 70 105 140

Subtotal 1 185 24a 200 os 35 Fe

Technical and Engineering

Waste 1 203 4 1 2 3 4

Radiochemical 202 3 4 2 2 3 4

Instrumentation and Controls. 2 «238

Performance, reports, nd 47th

techni =~ -.it2L22 % %#

Subtotal 9 23 % % 8 3 0 %

Tow! 252-396-423 524 259345440537

---Page Break---

TABLE 31.10.13

STAFF REQUIREMENT FOR COAL-FIRED PLANTS

WITHOUT FGD SYSTEMS,

eee

400-700 MWe) Unit 701-1300 MWie} Unit

Units per Ste = Uns per Se

voz 3s 4 a a

2s a

Plant managers office

Manager Por rp dr rg

Assistant 10203 4 1 2 3 4

Environmental control Por er dG

Public reations Por or rr a ag

Training Por rr bd ag

satety Port ry as

Administrative services 2013 4 15 12s

Health services yororoz 1 4 4 2

Security 7 7 8 @ 7 7 8 48

Subtotal 2 2 RB 0 2% 2 » wo

Operations

Supervision (excluding shift) 2 2 @ «4 22 ag

Shitts 45 50 60654550 606s

Fuel handling 2 12 2 1 2 2 8

Subtotal so 64 76 B78

Maintenance

Supervision 6 6 8 0 6 6 &

Cratts 7% 90 100 110 8 95 105 115

Peak maintenance annualized 326496 «128-28

Subtotal 113 160-204 248 118165209253

Technical and Engineering

Radiochemical 202 3 4 2 2 3 6

Instrumentation and controls = 2 «23g

Performance, reports, and

technicians Bw wom w we a 2a

Subtotal 6 9 4 @ © n 7

Total 24 271 336 404-222 27934412

See

---Page Break---

?The fixed portion of the maintenance cost of

44 mechanical draft wet cooling tover has been calculated

to Se $30,600.00 (1978 dotars).

?The inclusion of an FGD aystem in the plant

Aavolves a considerable addition to the staff. The

requirenents of total maintenance materials for this systen a

fyprosimately equal to the cost of che

required additional staff. One third of this cost Se

considered feed and the rest variable.

The fixed maintentnce cout is, therefore, given

by the Foltoving equation.

xed wasnt. cost = [(0.75)(0.45) 180 + $20,600.00

+ oan anso] a+ 0

here:

TSC = total staff cost

$30,600.00 = fixed maintenance cost of a vet mechanical

cooling tover (evaluated at 1978)

arse = cost of the additional staff required for

the plant with an FCD systen.

Variable Maintenance

?The variable maintenance cost is conprised of the

renaining 252 of the total maintenance materials, plus

the variable maintenance cost of the wot cooling tover,

plus the additional portion of the differential staff

cost for the FGD aysten.

?The variable maintenance cost of the cooling

m1-39

---Page Break---

tover is proport

mal to the kuchr generation ond

has been figured ly the United Engineers and constructors

fo de 0.0049 milts per kwhr at constant plant load Factor of 802 (1978 dollars).

The total variable maintenance cost is

th

srefore given a2:

Var. maine. cone = [(o.25)(0.489 (050) +

L i000

rene a 80H oF + (0x62 CaSO]

ate?

Fined and Variable Supplies and Expenses

4) Fixed supplies and Expenses

This cost category includes all materials and

expenses that are of an expendable nature such as

chemicals, lubricants, make-up fluids and gas records, contract services, etc., and is proportional

to the net ai

ition KW rating.

?The equation for this cost category is:

Fixed § § E = (Per unit cost) (Ku)(1 +e)?

?The per unit cost for a coal plant has beon

determined as $1.30/kw (1978 dottars). 22

») Variable Supplies and Expenses

?The variable supplies and expenses include the

costs of Line and limestone and the sludge disposal costs «

A Limestone wet scrubbing system is used in this

study since limestone is abundant in the northern

art of Puerto Rico between Isabela and Bayanéa and

---Page Break---

3.11004

represents an attractive low cost local resource.

Approximately four tons of Limestone are required

for every ton of dry sulfur content in the coal. 1

< combined

five tons of dry sludge are aixed with an equal weight

amount of vater to produce ten tons of wet sludge.

Lf P, is the price of Lieestone in §/ton and Peg the

disposal cost of a ton of wet sludge by trucking

(excluding layering and compacting in the land £111

aperation), then the variable supplies and expenses

For the $0, removal aysten are evaluated as follow

Var. § 6 E for $0, removal = ?ST,(4P1 + 10Pgq) x (8760XCF) ater

where:

cr = capacity factor

S = Por unit sulfur content in coal (2/100)

Tz = coal firing rate of the boiler (tons/hr)

= Cost of Limestone ($/ton)

A

Pag ~ Cost of sludge disposal (3/ton)

Insurance

Fossil fueled pover plants in Puerto Rico carry only

property insurance vhich is a function of capital investnent-

Payment of this insurance is covered by adding the

m4

---Page Break---

Tot.

corresponding percentage to the Capital Recovery Factor.

rast experience shows that in Puerto Rico this factor

has fluctuated between 0.33 and 0.40% of capital invest=

Public Liability insurance for power plants in

?the PREPA system is generally taken care by an in house

fund. It is difficult to determine a fixed charge for

Public liability insurance, therefore, no specific charges

are made for this iten.

3.16105 Admini and General Expenses (ASG)

It is estimate? that the ASG expenses for plants

with FOD systems equals 10% of the entire fixed cost

That is:

ee

Ts¢ = Plant State Cost

FIXMAT = Fixed portion of mai

FIX S6E = Fixed portion of supplies and expenses cost

atsc + Differential staff cost required for the

Pop systen

3.1,10.6 Summary General Equation for 06M with P60 systen

In summary we have the folloving get of equations:

Statt cose = flrse + arse]: (1+

Foxed taint Goat + [0.38759 Sc) + 20,600 + (0.33) (atscj (140)?

Var. Maine Cost = [(0.1125) (TSC) + 9.0049 (wir) (0.80)+(0.67) (ATSC)] (1+e)?

t 1

Fixed S6E = [eso an) a+ 0

Var. sé = [£79 GP} + 10Pg4) (8760) (cF)] (1 + &)?

AiG Expenses = (0.10) [75C + Ats¢ + (0.3375) T8¢ + 30,600 + (0.32)

(arse) + (1.30)KW)] (1 +e)?

o-a8scas0) + 0.139 730) + 3060 + 0.19 60] 41"

m4

---Page Break---

Adding and conbining

ras ve get:

Total 06 M Cost with RGD System = /1.584) (TSC) + (2.133) (ARSC) + (4.9 x 10°6)

(Cewne)(0.80)+(S) (Z_) (4P1 + 10%y4) (8760) cF

+ (1.43) Ga) + 35,966) + ey

?The 06M costs of the FGD system included in the above equa

ton are computed by the folloving formula

O&M cost (FED Syst.) = [(2,133) @TSC) + § T,(4P,+10P?Q)x

(8760) ¢cF)] (ae)

2.1,20.7 Leveltzation of Operation and Maintenance Costs

Operation and esintenance costs, like fuel coste are

subject to inflation during the life of the plant.

1m order to have the operating and maintenance (0%)

charges on o levelized basis during the Life of the plant,

so that At can be added to the fine? capital investaent

charges and levelized fuel charges a levelizing factor has

to be considered, The sane levelizing factor described in

Section 3.1.9.2 can be used provided the correct total ia-

lation value of w is used for the O6M charges. The Leve-

Hsing factor to repeated here os:

beGemta .

Saerar a

where:

ro oeieu

ee

= yearly average of the weighted total inflation rate for tthe OGM charges during the Life of the plant.

?The levelized OGM charges during the Life of the plant,

in mills per kilowatt hour, is therefore, given

06M charges (aille/kwhr) = 06M co)

tea

ura

---Page Break---

3.1,10,8 Sample Calculation for » 450 1 Coal Plant for PREPA

The cost for an average pover plant staff meuber to PREPA is

calculated as §26,000.00 per years,

Prom Table 3,1,10.1 the sumber of persons needed to ope~

rate one coal fired unit is 214 and the differential staff

for the $0 renoval systen is 38.

SC = ($24,000,00) (214) = $5,236,000,00

?ATSC = ($24,000.00) (38) = § 912,000.00

wre 22

Assume: Py = Pug = $5.50/ton?

ce = 152

s oo

% = 200 tons/hr (based on 9,800 Btu/kwbr heat rete

?and 11,000 Btu/2b coal)

e = ye

Y = 1985 - 1978 + 7 years

oral O6M cose = [(1.584)(5,136) +42.133) (912) + (4.9 x 10°)

(430) (8760)(0.80) + (0.03) (200) (14) (5.50) (6.760) 0.75) +

casas caey + 33.08]00)%C.057

= $23,666,000.

?Actual average base salary obtained ty Gividing totel salaries by total staff is $12,128.00 per person. Normal office hore in?REPA are 7 1/2 Dut ohife personnel work on 8 hours shift. Operators have to work an average of 8 1/2 houre to transfer the shift to the incoming operator. ?The extra hour is paid at a double rate which makes the shift personnel working day equivalent to 9 1/2 hours. They get an extra pay equivalent to 26.7% of their salary. In addition, all holidays worked are paid at ?a double rate and eubatitution for sbeentees and sick employees adds the overtine pay. Canceled meal tines due to energencies are paid at a triple rate, Evening andnight hifts have additional differential pay. Fringe benefite add 52% to basic salaries and overtine pay accounte for approxinately 26% of extra charges on increnental fringe benefits. The~ refore, the total multiplier for average salaries in @ power station where shift personnel is davolved, is close to 2.

mr4

---Page Break---

?The total generation at 75% capacity factor

(414,000) (0.75) (8760) = 2.71998 x 109 kwhe

?The total OSM cost in nills/kwhr levelized for the 35

years plant life using the sane levelizing factor

fuel (1.81, inflation factor of 5% per year during plant

Lifetime and i at 9% per year) is then:

for

9

Total OM Cost 23.656 x 10!

T7998 107 * 1-81

Total Os Cost = 16 mitle/kube

For operation in 1985.

The first year O&M cost is 8.70 milis/kvhr.

06M costs included above are 3,14 mills/kwhr for the first

year of operation (1985), and 5.68 aills/kvhr levelized

for the 35 years of plant operation.

?The cost of operation of the FGD System is included in the

$23,666,000 figure. However, the FGD operation cost can be

calculated separately from the relation at the end of

section 3.1.10.6. This separate calculation gives $8,535,935

(1985 dottars) for the operation of the FCD system. The

operating cost of the plant without FCD system would then

amount to $15,130,065 (1985 dollars). The ratio of total

?operating cost of the plant to the operating staff cost is calculated a8 follows:

Ratio of OGM cost to Plant staff cost =

$15,130,065

(Plant without Fep Systes) 6,136,000) 1.08)?

Ln

and

Ratio of O6M to Plant Staff Cost = 23,666,000

(lant vith FOD System) 048; 000571208)?

= 2.28

?The ratio of total operating costs of the plant with FoD

systes to the total operating cost of the plant without

FoD system is

Ose cost of plant with FD . 23,666,000 . 1.56

15,130,085

Oi cost of plant without Fab

mms

---Page Break---

3.1.11 Sumary of Total Coste of one 450 MW Plant at Rincon

Sith FD System

The total levelized costs during the assumed 35 years

Lifetine of a 450 Mf coal plant (Rincon Site) at 75% capacity

factor, with an POD System, a 9% cost of money, a 5% total

inflation for cost levelization in fuel and in 06M is:

Capital charges + 23.8 mille/kwbe

Fuel Cost 5 $6.11 mills /kwhe

osm, 16.0 mille/ewhe

Total + 95.9 (1985 stare up)

Escalation at 52 per year of all the above costs is shown in

Table 3.1-11.1

TABLE 31.111

LEVELIZED TOTAL COSTS FOR PLANT START-UP

IN YEAR INDICATED

WITH 58/YEAR INFLATION BEYOND 1985

?StartUp Year 1985 1990 1995 2000 2005 2010 2015 2020

Levelized Cost in Mills Kut 959 1224 1562 1994 2545 3248 4145 5290

If an inflation factor of 7 1/4%/yr. beyond 1985 is

used for fuel as well as for O&M, the levelizing factor is

L = 2,508, The 1985 cost changes as follows:

Capital charges = 23.8 wille/ewhe

Fuel Cost = 17,16 wills/eehe

os = _22.07_mils feshe

123.63 mills/kwir

mre

---Page Break---

Table 3.1.1.2 indicates the levelized total costs for

Gifferent start-up years.

TABLE 3.1.112

LEVELIZED TOTAL COSTS FOR PLANT START-UP

IN YEAR INDICATED .

WITH 7-1/4%/Y EAR INFLATION BEYOND 1985

Start-Up Yeor	85	90	95	2000	2005	2010	2015	2020
Levelized costs in mills	1237	1755	249.1	3535	501.6	711.7	10099	1493.1

ry

---Page Break---

10000 Figs 31-11

Total Levelized Cost (aills/evk)

450 vie Coad Pant vitl FED fyocen?

Plant Investeent Escalation 1978-45; 61/¥e.?

Goal _zacaletion 1978-85;

Plane seare-0p Year

2020

---Page Break---

Beez

ample of @ Two 450 Yi Unit Coal Plant at Rincéa with FoD

System

?The total per unit generating costs are reduced when ore than one pover production unit is located at the same site. The economies of scale result from the following fac~ tors: port facilities and other site developnents can be shared and used optinally, there are economies in design, engineering and in construction if the units are constructed on a afsultaneous construction schedule with the second wit lagging the first by no sore than one year, there are alse savings in operating and maintenance costs since soae of

?the personnel can be shared between the two units.

Capital Charges:

?As show in Section 3.1.8.4 the basic cost for a 450 1!

coal unit plant is $683/KW for the base year 1978, Econonies

in the construction of the second unit will amount to an ov

all reduction of about 5% in the unit cost. Therefore, the

basic capital cost of a two unit plant is estimated at

s649/e.

The added costs K include

Total port facilities 384,000,000

Waste disposal plant

at $15.00 per gross KW 13,500,000

397,300,000

---Page Break---

K+ 97,500,000 = 117.8 $/kw

828,000

C= (Ktc0) Tp TO) 2 tye 2%

For 1985 operation, with Ty = 1.08, Tye = 1.09

= (649 + 127.8)(1.373) (1.262) = $1349.71/901

(Cost in mit6/Kuhe (1985)

= 20,3 wilts/Kuhr

Fuel Costs:

?These vary Linearly with output and therefore no econo~

nies result from a two unit plant.

With a 5

scalation rate after 1985

Fy = 56-21 wilis/Kvhe

With a 7.252 escalation rate,

FL + 77,76 mitte/kvnr

Operation and Maintenance Costs (08M):

Froz Tables 3.1,10.1 and 1a, the number of persons needed

to operate two coal fired units is 271 and the differential

ie 65.

staff for the S0p removal 5

5c = ($24,000)(271) = $6,504,000

AzT80 = ($26,000) (65) = 1,560,000

velltzing:

© = 8t/year

1-50

---Page Break---

cre 732

sx

Ty = 400 tone/he

Y= 7 year

"1 * Pap $5-50/ton (Section 3.1.0.8)

Fa.s006,s09 + (n13901,560 + 49 wa x

8,760 X 0.75) + (1.43 x 900) +33.66] ao}

(1.08)?

Total OSM Cost = $21,052,061 (10)3(1.08)7

= $36,079,533,

Generation at 75% CF = (828,000 x 0.75 x 8760)

= 5.43996 x 109 ame

The total O&M cost in mills/KWhr using sn inflation

kate of St/yr for the levelizing factor is:

Total OSM Cost =35.080_x 109 x 1.81

3996

= 12 ills ome

costs during the 35 year

Lifetime of a two 450 MW unite coal plant at Rincéa

with 75% capacity factor, FOD System, 9% cost of

msi

---Page Break---

soney, 5% total inflation for cost levelization is

Capital charges = 20.3 mills/ewhe

Poel Coste = 56.11mil Le ewe

osm costs = 12.0 wi2ts eve

Total 1985 Cost (Levelized) 88.41 wills/iwhr

Table 3.1.12.1 shows the levelized costs for the two unit coal plant at RineSa with different

start up years and a 5% inflation rate for all costs

beyond 1985.

TABLE 3.1121

LEVELIZED TOTAL COSTS FOR PLANT START-UP

IN YEAR INDICATED FOR A TWO 450 MW UNIT

COAL PLANT WITH 5% PER YEAR INFLATION RATE BEYOND 1985,

Star?Up Year 1985 1990 1995 2000 2005 20102015 2020

Levelized Cost in Milis;KWhr 88.41 112.84 144.01 183.90 294.60 299.39. 362.10 487.67

Assuming an inflation rate of 7.25% beyond 1985

for both fuel and O&M costs, the levelizing factor L is

2.508. The total coste for 1985 are as follovs:

Capital charges = 20.3 mils /ewhe

Fuel Coste = 77.76 wilis/ene

06M Costs = 16.63 silts /iewhe

Total 1985 Cost (Levelized) 114,69 wilis/iwne

nrsz

---Page Break---

Table 3.1.12,2 indicates the levelized costs for

the two 450 Mi units plant at Rincéa with different

start-up years and a 7 1/4% inflation rate for all costs

beyond 1985.

TABLE 3.1122

LEVELIZED TOTAL costs

FOR A TWO 450 MW UNIT COAL PLANT

START-UP IN YEAR INDICATED

WITH 7.1/4% PER YEAR INFLATION RATE BEYOND 1985

Start-Up ¥	1985	1990	1995	2000	2005	2010	2015	2020
Levelized Cost Mills/KWhr	114.69	162.75	230.94	327.71	465.02	659.87	936.36	1928.71

---Page Break---

He. 3.1.32

wo 450mie Unit Coal Plant with FOD systea

Plant Investnent Escalation 1976-65: 82/Yr. -

(Coal Escalation 1978-85: 7 1/43/¥r.

(OGM Escalation 1978+

tion: 92/Ye.

ate: 9,8636%

Escalating Rates Beyond 1985 as indicated

?TOTAL LEVELLZED OST (ailts/hvh)

---Page Break---

This section presents an analysis of the construction,

operation and saintenance costs of a nuclear pover plant in

Puerto Rico.

AC present, there are basically two types of nuclear

Power plants commercially available in the United States.

Boiling Water Reactors (SYR) and Pressurized Water Reactors

(PuR). Both systens use slightly enriched uranium

the fuel,

and water as the noderator and coolant.

?The analysis considers both options with enphasis on the

PWR and estinates the costs for the three categories of capital

investment, fuel and non-fuel operation and maintenance.

3.2.2 Nuclear Plant Capital Investment

Appendix D contains detailed capital cost estinates for

nuclear plants. Various cost estinates are presented for

nuclear plants as follows:

() New 585 tiie nuclear plant at a site in Northern Puerto

Rico, Source of direct cost data estinate is PREPA

Consultants?? and source for estimating costs of engi-

neering services construction management and other

indirect costs is uesc. 9139134

The unit cost is:

S775)

(2) New 585 mie nuclear plant at a

?ite in northern Puerto

Rico. Source of data is PREPA Consultant Engineers in

its entirety, 12

The 1978 unit cost is: $894/KH

(3) NoRCO Unit 1 reactivated for operation in 1986, source

of data is PREPA consultant in its entirety.!

The 1978 unit cost is: $817/Ku

mss

---Page Break---

@

o

1139 Mie PHR Nuclear Plant at a eite in Puerto Rico.

Source of data is United Engineers 6 Constructors-NUREG-

0241.39

The 1978 unit cost is: $685/kW

1190 Mie BWR Nuclear Plant at 2 site in Puerto Rico

Source of data is United Engineers & Constructors-NUREC-

024234 The 1978 unit cost is: $670/kw

Im addition to the above estinates, other sources of

data and their estinates are as follows:

ay

@

o

EPRI ~ Report PS-866-SR June 1978

cost data for 1000 Mic nuclear plant vas developed by

United Engineers and Constructors. It constitutes the

sane source of information as the estimates already

quoted. Cost for the most comparative Puerto Rico site,

the southeast United States is comparable with the Figur

already quoted.

Gibbs & Hin, Ine.!?

A total cost of $583/KW (1978) is quoted for a two unit

station 1150 MWe, including indirect expens:

+ engineer-

ing construction management and contingency.

ona

?The Institute for Energy Analysis presents an estinate

of $500/KW for @ 1-1000 MMe nuclear unit based on 1975

dollars. hen escalated to 1978 at 8% per year the

cost is $630/kW.

---Page Break---

ORAU~76-3 also presents the following estimates:

TABLE 3.2210)

NUCLEAR PLANT COST ESTIMATE

orau-76-3)9

Dollars of 1985 Dollars of 1978

(1985 costs deflated at 8%/yr).

United Engrs. & Conse. ?980 ?554

Bechtel 1030 601

Sargent & Lundy 1005 586

General Electric 953 556

Skagit, Washington 1030 601

Tyrone Park, Wis. (BOOMW) 816 535

carrot County 2, th 686 400

Davis Besse (906M) 865 505,

Greenwood 2, nd 3, Mich. 820 479

(2x 1200 MW)

mts?

---Page Break---

?The UEEC cost estimate presented here was the result of

Mr. J.H, Crowley's staterent to the Connecticut State Public

Ueility Control Authority in January 29, 1976. These UESC

estimates are therefore superseded by latter detailed cost

by UESC presented elsewhere in this report. The

estimates presented in Table 3.2.2a were found to be on the low

side and will not be used in this study to estimate nuclear plant eotinats

capital costs. Those points where plant sizes are indicated are

shown plotted in Figure 3.2.2,

For this study only the highest reported estimates will

be used.

Table 3.2.2b summarizes the capital cost data and curve

£i¢ used in the nuclear plant capital estimate for this study.

TABLE 32.2.(0)

CAPITAL COSTS ESTIMATES

(1978 DOLLARS)

siKW Source and Date

508 PRWRA (2) ~ 1979

685, UESc = 1979

670 ueac =~ 1979

Exponential Fit (500-1200 mu): $/M = 11825"0-000478%68

eo

Figure 3.2.2 presents

Plot of the nuclear plant invest~

ment cost equation.

The general cost equation can be expressed

© = 82g" 0004781 yp t+ Clea) Wp 1, ap

mmrs8

---Page Break---

1978 ¥/?w Capital Investment-Nuclear Co

9007 GT PRWRA consultants

estima Fig.3.2.2 Copital Costs Nuclear

Plants 1978 dollars

Gorcoterwn cons >

OT PRWRA-UE &C-CEER

This Study

Co*nez ¢~.000470 MW

700}

UE a C-CEER

NUREG 241-0242

ooh. cine a

gtvrone pork (ne)

tone)

(orau)

?rook. Greenwood 2and 3 (mich) >

?Senay

uw

1-59

---Page Break---

where Te, Tyg Yys Yps and a are defined in Appendix E.

K are the plant cost adders not ineluded in Co,

?The cost in mills per kwehr is given by: mills/kwhr = _(C) (CRF)

CECA)

wher

CRF = capital recovery factor plus other costs of money

(See Section 3.1.8.1)

CF = plant capacity factor (See Section 3.1.8.2)

For a 585 Mie plant, 1985 at a north co

site in Puerto Rico

-0 Y= 0

as ue y o7

y= 1.08 CRF = 098636

Tye = 1-09 ce = 0.75

co» $894/twr (1978)

YtG-a¥y, = 3.64

at = 3.36

1985 investaent cost

© = (894) (1.08)?+*(1,09)3+36 = g1580.35/40

cost in mitte/evie = 1580-35) (2098636) «95.75

3.2.3 Nuclear Fuel Costs for Puerto Rico

3.2.3.1 General

?The evaluation of fuel costs for nuclear plants

is a rather couplex operation. Figure 3.2.3.1 indicat

?the various steps involved in the nuclear fuel cycle.

---Page Break---

FIGURE 3.2.3.1

THE NUCLEAR FUEL CYCLE

FUEL

FABRICATION

REACTOR

MINING

INTERIM

SPENT FUEL

STORAGE

PERMANENT

WASTES ____ | WASTE

DISPOSAL

TI-s1

---Page Break---

Uraniua is widely distributed in nature at very low con

centrations in the order of 2-4 ppm in the earth crust and .003

0 .004 ppm in the oceans. Coal, lignite, tar sands, shales

and oils are also sources of uranium with higher concentrations

in the order of 50-200 ppm. Commercial deposits of high grade

uranium are in the range of a fraction of a percent, some as

high as .75%. The alning costs

the ore concentration.

1e inversely proportional to

?The diluted uraniun ores

re concentrated in mining

?operation to 85% uranium through a series of physical and

chenical process

fora of U30g, a yellow clay comonly called yellow cake.

?The 85% uranium concentrate is in the

The yellow cake at 85% Uj0g concentration is the normal-

ly available source of uranium in the opne market. On 1979

the cost of yellow cake is approximately §35-40 per 1b.

Uraniua, as a commodity, is strongly cost sensitive to

?the supply-demand relationship. The predicted needs for uranium

are therefore important to predict future uranium costs.

This vill be considered later.

?The uranium cake purchased from the various private

suppliers must be sent to Government plants for conversion te

Ure, @ green salt. This material is euitable for use in gaseous diffusion plants in which the UF, is converted into @

gaseous phase for physical separation of the isotope U-235.

In these diffusion plants the natural isotopic content of U-235 (0.7%) is increased to desired concentrations in the order of 3% for use in light water reactors(LWR). The depleted uranium tails contain normally 0.22 of the valuable U-235, Charges for conversion are made in terms of dollars per Kg of EG. Charges for enrichsent are made in teras of dollars per

---Page Break---

rative work units ($/SW)). A separative work unit is a

lueasurement of the anount of work performed by the diffusion plants in separating U-235 (the useful fissile material) from the bulk 0-238. Depleted uranium tails at 0.2%-U-235 and enriched uranium at ~3% (for LWR) are discharged.

?The enriched uranium output from the diffusion plant is jn the save chenical form as the uraniua fed in, i.e. UFy.

The enriched UF, is then processed by the reactor fuel element manufacturer and converted into U0), a black powder.

?The use of UO, as a nuclear fuel was one of the greatest achievenents in nuclear fuel element development during the early part of the 1950-1960 decade. U0, is highly stable physically and chemically under intense and prolongued irradiation. Its melting point is close to 5000°F. Tt has an acceptable thermal conductivity coefficient. Te exhibits

fant negative ouclear reactivity coefficient (Doppler coeffi~ cient) thereby holding dow any nuclear pover excursion and shutting down the reactor automatically; this is an important safety consideration. Most important, it has the property of retaining a large fraction of the gross highly radioactive Manion products within ite matric, only releasing the gaseous products into the cladding or sealed stainless steel fuel tubes within which the UO, fuel resides.

?The UO, powder is compacted to densities higher than 95 theoretical, and then pelletized into snall cylinders. These pellets are used to fill up stainless steel or zircalloy tubes.

?The tubes are weld sealed and form vhat is know as a single fuel pin, Various fuel ping are assembled into what is called

4 fuel assenbly. The cost of manufacturing fuel assemblies is

normally given in dollars per Kg of uranium manufactured into

the assenblies,

n1-63

---Page Break---

After the fuel assenblies are used up in a reactor to

Produce useful pover, they must be stozed for @ cooling period

4m a fuel pool within che reactor building. After this they

are finally transporsed in shielded fuel coffins to reprocessing

plants where useful by-products (plutonium and unused uranium)

fare recovered, Tie charge for this portion is post operation

al charge and is normally expressed in $/Ky of uranium dispost

the recovered uraniun and plutoniu can be recycled én the reactor resulting in reduced costs. In thie study no recycling is assuned.

Pressurized Water Reactor (PWR) fuel cycles normally operate on three batches. At each refueling operation, Perforned once a year, one third of the fuel asseablies are recovered and replaced with new fresh fuel assemblies, and the renaining fuel assenblies are ceshufled within the core.

After the first three years of operation all the assenblies

Feach equilibrium conditions. Each assenbly remains in the core for an average of three years or three refuelings after equilibrium condition is reached. The Boiling Water Reactor

(Bik) operates on a four batch cycie.

Specific fuel burn-up value for a PWR reactor is of the order of 36,000 Mi-days per metric ton of uranium. Therefore 4 reactor of 600 MWe (equivalent to 1785 Mi thermal) operat~ ing at a 75% plant capacity factor (275 day operation at full Power per year) will generate 490,875 Mi days and will require fan uranium loading of 13.6 cone. One third of this amount ?must be replaced yearly. the total dollar inventory tied up in the reactor fuel can be calculated by multiplying the above energy by the unit cost of energy excluding indirect charges. This cost is calculated to be $29 million dollars

at the rate of 72.4 cents per million BIU. Interest charges

---Page Break---

?must be accounted for this inventory. These are the indirect charges.

BWR reactors have specific burn up lover than PWR, Values Just slightly under 30,000 Mio/ton are typical for ByRS.

The discharged spent fuel elements are stored for a cool- ing period in a fuel pool designed especifically for this Purpose. After six months of cooling dow, the pent elements ?can be shipped in specially shielded casks to reprocessing

plants for final disposal. Present NRC regulations con- cerning final disposition of nuclear wastes are under review.

Recently, a contract design avard vas announced to

Bechtel for the d

ign of a $3 billion nuclear waste solidi~

fication facility at DOE's Savannah River Plant near Aiken, 8.c.°> this facility vould immobilize high Level vastes into @ form suitable for permanent disposal.

The fuel pool could be designed and constructed at little added cost to store tenporarily all the spent fuel element assemblies discharged during the 1ifetise of the plant. By that time, many different methods of waste disposal now under design and consideration will have been worked out. The TVA hhas designed large fuel pools into their ri

willing to offer interim storage for spent fuel elenents to the industry at @ small charge. UESC estimates at $8,700,000 the extra cost in fuel pool expansion for high density interim spent fuel storage of Lifetime discharges of a 1139 MWe PUR reactor plant vith 33 refuelings,

?The problen of spent fuel disposal is not an insurmount~

able problem.

3.2.3.2 Nuclear Fuel unit ¢o

?A Lenghey and complex calculation is involved to deter-

mrss

---Page Break---

mine the total fuel cost in cents per million BTU.

Computer programs are available for detailed cost calcu-

lation, and detailed "forms" are available for hand

calculations.*© of particular importance is the treat

ment of indirect costs or cost of money charges for the

capital allocated for the nuclear fuel,

Simple and accurate calculations can be made

with certain derived coefficient obtained from sensiti-

?The degr:

for the purposes of this study. The coefficients to be

vused in this study only apply to Light water reactors

and are more exact for. pressurized water reactors.

Average heat rate of the nuclear plants is considered

co be in the 10,200-10,300 BTU/kwhr net range. Fuel

burn-up of the order of 30,000-35,000 me per ton of

uranium are typical of these types of plants. The fuel

vity calculation

of accuracy is good enough

cost coefficients are good for equilibrium cycle

costs. The small first core increased cost is neglected.

The following are the cost components (CaPy)

and coefficients (C,) as deternined from sensitivity

9,28,36 a!

analyses

) 30g (vettow cake) cost component (C1Py)

309: S/M@TU = .00673 x U;0y Cost in

ab.

(2) UFe conversion cost component (C2P,)

Fg: $/M@TU = ,005696 x Conversion Cost 3

ibs

(2) Separative or earichnent cost component (C3?)

Barichnent: $/M@BTU = .00166 x (S/sw)

(4) Fuel fabrication cost component (C,P,)

Fuel Fabr.: $/@@TU = .0909174 (Sof Fabr.)

1b

m6

---Page Break---

(5) Spent uel shipping and Disposal (¢5?5)

(ssp): _$_ = 0003957 x C$. of ssp)

mor =

(6) Indirect Costs

?The indirect charges consist of the interest

paid on the dollar investment in the fuel core which

hhas been made for a rather long period of tine before

actual useful energy is produced. This is really a charge on an inventory. The indirect charges can be divided into two parte:

(a) charges for the investaent tied up in the nuclear core while it is operating and producing pover. These charges are sensitive to the plant capacity factor. The lover the plant capacity factor, the longer the tine period and the greater the charges will be, This cost will be designated ¥,

(b) charges for other non-operating periods of tine which can be considered approximately constant on

the average. This cost vill be designated My.

The indirect charges during operation My can be expressed a:

(49783

my = CATER. Gay. Ceyry + yr, + GPs + 02) where i= interest of money or cost of money

CF = plant capacity factor

?The indirect charge for the other non operating period

can be expressed as:

My = (628)(T9) (G) » (CyPy + 62Py + CBP + 0,24 + C5P5)

where T, = tine in years required for ordering 0503,

and UF, enrichment. It can be taken ae 1.5 years.

m1-67

---Page Break---

?The factors of .48763 and 0.25 provide adequate levelling

of the funds expenditures during the respective periods

considered.

?The total fuel costs in $/MMETU can be express-

ed as: Fuel Cost Equation

Total Cost $/METU = CP, +

2

3.2.3.3. Gost Component Estimates

(a) Yellow Cake Uy?y market predictions

The cost of yellow cake is highly sensitive to the law of supply and demand, a was indicated previously. Assessment of the demand is therefore, very important in determining costs. Larger deaands neans exploitation

of less economical (nore diluted concentrations) uranium

deposits, and therefore, higher costs.

Table 3.2.3.34 taken from the EPRI report indi~ cates predicted uraniun demands.

TABLE 3.23.3 (0)

URANIUM REQUIREMENT ESTIMATES*

(U30g ~ 1000's short tons-2% tail)

No Recycle

1980 170

1985 278

1990 408,

1995 680

2000 983

* Based on 5.2 x 10! kwhr electrical generation

by the year 2000,

1-68

2 TOs + OW, + OPS ML +

---Page Break---

Figure 3.2.3.3 indicates the S.M. Stoller correlation

Of cumulative production or demand vs. estimated price taken

also from the EPRI report,

>)

?An extensive survey of the Literature was per-

formed for cost predictions.

?A tabulation sumary of the cost survey is

Presented in Table 3.2.3.36. It should be pointed out

that the references, 29-PREPA consultant $.M. Stoller,

McRPRT, and 38-PREPA are all-based on the sane source,

namely 5.M. Stoller.? The variations might be explained

by different escalation rate assumptions between 1977-78

and 1985. The highest value of these three references

will be selected and aver

together with the three

highest of the resaining five references. However, if

?any of the remaining five references is lover than the

lowest S.M. Stoller based estimate it will be rejected.

Im this way an adequately weighted and conservatively

timate will be

higher chan any $. M. Stoller based prediction, which in

themselves are considered safe and conservative by the

high average estimate is provided. the

nuclear industry,

Table 3.2.3,3¢ illustrat:

costs analysis

che nuclear fuel

result for this study following the

mentioned procedure.

11-69

---Page Break---

stesoderp

ara eases A199; 268, 30, e8ae> suoreatnby ue 09 tena oq Tr3M S142 ?(aya) Tev6N Kneey 30

voa/pmHOOONE se Ie

Forge Menansay ?nteibt 400 s2H9> 12° Jo oBse4> rou v aw H3se0 AUTTO\IN apntouy MLMIDIVE

Oe ae ose ee

popmrouy #3609 ¢ast puv #2809 guéT uasmiaK 25 I

Bust94093 oN + (#3809 ps

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st} soot or - - ® st @ |cayeetiey asoaorer

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SStowNOS SaOIAVA KW S1SO9 3R4 WaIONN 40 AanNnS

eee

E70

---Page Break---

Us Og Price (dollars /pound)

40

200 400 600 800 1000 1200 1400 1600 1800 2000

Cumulative U0, Production (thousands of short tons)

Figure 3.2.3-3 UsQg Projected Price Based on Production:

Costs In End-of-the- Year 1977 Dollars

SOURCE: EPRI P5a866-58 5

pecial Report. Technical Assesssent Guide, June 1978 (14) * Gatdes

nr71

---Page Break---

TABLE 32.3.3 (c)

NUCLEAR FUEL COSTS ? PRESENT STUDY

TT 1985 Fuel Comte

Extimated Unit Costs Calculated S7MMBTU

?Ore Cost Sf 61.50 ata

Conversion si 3.06 0.017

Sep. Work s/swu 127.87 0212

Fuel Fab. Sib 87.00 0.80)

Subtotal : 0.723

Spent Fuel Ship & Disp. 190.00 0.075

TOTAL este 0.798

Indirect Charges (1)

Operational time(MA) 0.042

Sersponon tun

severe ag.

(1) 7596 plant capacity factor is used.

(75% plane capacity factor is us

Tee cost in mille per kvhr can be expressed as

(sheer y Giese Rate)

() Escalated and levelized fuel «

Fasslated and levelized fuel costs

Fuel costs are to be escalated from the year 1985 to the corresponding start up year and then levelized for the life of the plane.

The ore cost vill normally escalate at a higher rate than ?the other cost components. The total escalated and levelized fuel cost will be expressed as follows (see Appendix £ for

levelizing theory).

mr-72

---Page Break---

Wuclear Fuel Cost in dollars/t@TU

+ [orrrareye)

1985

ye +

1985

1

[Goratearavcarascsesong) case)

*

@

ye

lye

= year of estimate » >1985

wcalation for yellow cake, ave. per year

= levelizing factor for yellow cake

= general escalation for material and labor

= levelizing factor for material and labor

= Pa

PH

Example calculation of fuel cost levelization

Let ¥ = 1985

?ye

i

= 7:1/4% (ave. yearly escalation of uranium yellow cake during

plant Life)

= 5% (ave. yearly escalation of other non-uraniua ore charges,

labor, materials, and services)

= 9% (cost of money)

From the above

?Eye = o16x2

aye

= Pufat.01632) = 2,508

m1-73

---Page Break---

ro du = 038095

ie

L = Pu(.038095)_ = 1.81295

PH (09)

Levelized 1985 Fuel Cost =

(414) (2.508) + (1.81295)(.453)

= $1.86/omry (1985)

with heat rate of 10,300 BIU/Kitt

Gost = (1.86)(10.3) = 19.15 mitts kvhe

mr74

---Page Break---

3.2.4

3.2.4

Operating and Maintenance (06M) Cost ~ LMR

Estimates for a Light Water Reactor Pover Plant are considered here

Operating and Maintenance Cost Equation

?The estimates for operating and maintenance (06M) costs developed here, are based on the ORVLATN-6467 report ?A Procedure for Estimating Nonfuel Operation and Maintenance Costs for Large Stean-Electric Power Plants" and on information obtained by personal comunications with UESC.

According to the ORNL Study, the nonfuel O6M costs for SUNK power plant are comprised of the staff cost, fixed sain~ tenance, fixed and variable supplies and expenses, insurance aad operating fees and adainistrative and general expenses t should be noted that the maintenance materials cost for a nuclear plant is a fixed expense and does not vary with plant

operation time.

(For an LR plant, the fixed maintenance cost has been

determined to be approximately 45% of the total staff cost). The maintenance costs for a mechanical draft, vet cooling tover has been determined to be $30,630 fixed plus 0.0049 sills per kvhr (1978 dollars).
?The fixed and variable supplies and expenses have been cor related vith the total net station electrical output and the total kilowatt hour generation respectively. ?The estimates

are §1.47 per KW for the fixed portion and 0.0356 mills/kwnr

nr75

---Page Break---

for the variable portion in 1978 dollars.

Nuclear power plant Licensees are required to maintain nuclear Liability insurance to a total financial protection of $560 million, according to the Price-Anderson Act. Of this total, a coverage of $140 million is available from com

nere{al ineurance pools. fn interaediate liability level

(called "retrospective premium") of §340 million, is provided between the private insurance and the governsent Liability Limits. The remaining $80 million are provided by the federal ?government.

According to the ORSL~T4-6467 report the associated annual

premiums as of June 1978 for one reactor (estimated in 1978 dollars) are as follows:

TABLE 3.2.4.1

ASSOCIATED ANNUAL PREMIUMS

Coverage $10 Premium $10?

Private Insurance 140 284

Retrospective Premium 340 6

Government Indemnity 80 S6/MWt(up to

'3000 mut)

?The operating fees are calculated at $100,000

per year, including the facility routine inspection fees

and the omner's inspection-related costs.

?The administrative and general expenses are

estimated at 15% of che total annual fixed costs, exclu-

sive of insurance and operating fees.

---Page Break---

The total annual operating and axintenance coute are the-

afore samarized as:

Toeat out cove § = [ise + 045 a86 + 30,630 4(4.9 x 10ré

% kw x 8760 x 0,80) + 1.47 x K+ (35.6 x 10-5 x KW x 8760 x CF)

+ 280,000 + 6 x mie + 100,000 + 0.15 (1S + 0.4SISC + 30,620

+1047 eo] asap

where:

TSC = total staft cost CF = capacity factor

¢ = average inflation rate of the economy 2/yr.

Y= number of years between estinate and commercial

operation

Rearranging the terms and adding:

Total O6M Cost ($) = (1.6675 TSC + 1.6905KH + (4.9 x 10°

* 8760 x CF x ks) (3.56 x 106 x hy x 8760 x CF)46 x MiEHH25,225) (Hhep)y

O&M Cost in mille/Kwh = ($044) /(KM) (8.78) (CF)

To obtain the operating and maintenance cost in uille/K¥h

levelized for the life of the plant, the above equation in

multiplied by the usual levelizing factor

(aem) [ase

wher

n= plant Life, yra.

Th

= weighted average inflation rate of the operation

---Page Break---

and maintenance costs during the n years lifetine of

the plant, 2/ye

rate of interest or coat of money 2/yr.

3.2.4.2 Specific Cost Calculation for?REPA 600 M8 PWR Power Plant

From Table 3.2.4.2 the staff required for this plant is

208 persons including 56 security personnel, This staff is

considerably higher than previous historic figures due to new

NRC security regulations. The average yearly cost per person

is $24,000 as indicated in Section 3.1; however,

Wornal 06M staff

timate the security personnel cost at $18,000.

The folloving paraneters are used in our example:

= 182

Security related staff = 56

Mie

of

or

= 178s

= KWe net = 585,000

+ 8t/yr (inflation rate from 1978 to
1985)

= 1985 ~ 1978 = 7 yrs

=e

= tye

= sty

= 0.038095 (from the relationship of

ri,

35 yes

m-78

---Page Break---

TABLE 3242

STAFF REQUIREMENTS FOR LWR PLANTS32

4200-700 MWe) unit 701-1300 MWe) unit

Unis pers Units pe ite

23

Plant managers office

anager |

Assistant 10203 4 1 2 3 4

ualeyesuronce 304 5 6 3 4 5 6

Environmental control Sr rr

Public relations Sn

?raining roy 2 2 4 4 2 2

satety ee

?Admiistrtve services Bo 7 8 8 8 oe

Health servins ror ot 2 4 12

Security SB 85 56105888

subtotal eT)

Operations

Suowrvsion excluding shit) = 2=«2 kk

Shits 2% 4% 68 BSF 5B 8] 108

subtotal 2 5 72 2 3 6 BF m2

Maintenance

Superision 2 8 2 8 8 w 2

Crate ?2 2B 1

Peak maintenance annualized $8110. 220 55 N10 165220, Subtotal n 40 210 79 148 att 298

?echnical and engineering

Reactor 102 3 4 1 2 3 4

Radiochemical 2092 3 4 2 2 3 4

Instrumentation and conoh «= =?«2 822k

Perlormance, epors,nd 17 at 28th

techniions vue RvR BB

subtotal nye H 2D Ww

TOTAL 208 300 909 S45 21531442050

Les security 152 244 342 440159253 364468

Les security and peak maint. 97134178 -220«108? 148199 2a

---Page Break---

Total O&M Cope = (1.6675) (24x152418x56)+(+.69054585)+(4.9x10°x8760

080x585) +(35610-6x8760x0. 75%585)4+(6x1.785)

+(425.225) 103(1.08)7

Total OSM Cost = $16,016,841.

ow

(58588, Tex)

= 4.47 mils /evh

This cost levelized for the 35 years life of the plant ist

0mm (Lev)

3.2.5

= Vaeseos5)25 1) F o,00ca,0035 |

02038095) @-os608s75 | | G.osy35 = T |

= GaN G.a1) = 7.55 mittee

Summary of Total Costs of One 600M Nuclear Plant at a Site in

Norther Pusrts Eee

The total 1985 costs are:

Capital Charges

is /kuhe.

Fuel .

of a 60006 Nuclear LWR Plant at 75% capacity factor, 9X interest

fon money, 5% ave. total inflation rate per year after 1985 except

for Uranium (Uy0g) which is escalated at 7 1/42 per year are as

fellows:

Capital charges 23.73 mills/kvhe.

Fuel a5"

om 255"

1985 START-UP 50.43,

(35 year levelized cost)

11-80

---Page Break---

The levelized costs for other start-up years beyond 1985

are given in Tables 3.2.5a,. b and © for different es

rates.

TABLE 3.2.50

?GOORR! LR PLANT LEVELIZED COSTS, ESCALATION 5% PER YEAR FOR ALL COSTS

?carts eR)

START-UP YEAR 1985 19901995 2000 2005 201020152020

costs 47.47 60.59 77.32 98.69 125.95 160.75 205.16 261.85

TABLE 3.2.5

{600MM LR PLANT LEVELIZED COSTS, ESCALATION S~ PER YEAR FOR ALL COSTS

?EXCEPT URANIUM (U30g) AT 7 1/4 PER YEAR

?OerLs aR)

START-UP YEAR 1985 1990 1995 2000-2005 «-2010«2015 2020

30g costs

GG isz ese) ? 10.69 15.17 21.52 30.54 43.33 61.50 87.28 123.84

AI others:

Gry) 7 50.72 64.73 82.62 105, ways, 219.21

TOTAL 50.43 65.88 86.25 113.16 148.77 196.07 259.03 343.05,

TABLE 3.2.5¢

(OOM LAR PLANT LEVELIZED COSTS, ESCALATION 7 1/42 PER YEAR FOR ALL COSTS

(ais /xmiRy

START-UP YEAR 1985 1990 1995-2000 200520102015 2020

MELLS/MR 56.58 8O.2F 113.93 161.67 229.41 325.53 461.96 655.49

Figure 3.2, indicates the plot of the above tables.

11-81

---Page Break---

FIGURE 3.2.5

10000 a

? G0ikie Nuclear tase :

Plane Tavestaeat Escalation 1976-05: 8/tr, =

_ Nuclear Fuel Escalation 1978-85: 1985 Basie

06M Eecalation 1978-65: 62/¥e.

(Sa oo nterest During Constructions 9t/¥e.

except tyQy at 7 W/Ar/te

Si conte

1985 19901985 2000 2005 2010 a

?plane Start-Up Year Pe ae 21s 2020

---Page Break---

3.2.6

Example of To 600 M6! Unit LKK Plant in Northern Puerto Rico

?The total Levelized unit cost of vo 600 Mi nuclear units

is smaller than that for a one unit plant due to econonies in

design, engineering and construction and in operation and sain~

tenance.

The costs are estinsted for a plant with an assumed Lifetime

of 35 years, 75% capacity factor, 9% per year interest charge

fon money, 5% per year average inflation rate after 1985, except for uranive (Uj0g) which is escalated at 7 1/4 per year.

3.2.6.1, Capital Charges:

The totel capital investment unit cost for a tvo unit plant

is estimated at 95% of the cost of the one unit plant. However,

4an aéditional year is added to the construction schedule so

that the second unit will begin operation in 1986. The cost

Will therefore be escalated at St for the additional year to

be consistent with calculations for the other energy alternatives.

The capital charges are 23.67 mills/Kvhr.

3.2.6.2 Fuel cost

The fvel coste previously estimated for one unit are

lated from 1985 to 1986 for the second unit at SE except for U;0, which is escalated at 7 1/4% and then averaged. Thus, the fuel

---Page Break---

(0,424) (2,508) (1.0725) + (2.81295) 0.453)(2.05) = $1.98AomTU

966)

L

+ 1.98 = §1.92 wry (Levelized average)

z

with heat rate of 10,300 81U/xvhr

Fuel cost = (1.92)(10.3) = 19,78 mills/kuhe

3.2.6.3 06M ©

According to Table 3.2.4.2, two 600 ¥H nuclear unite will

have @ total staff of 200, including 56 security related

personnel.

Total O&M cost ($) = (1.6675 TSC + 1.6905 KW + 40.5 x 10-6 x

?8760 x CF x KW + 6 x Mit + 540,449) (1.08)7

(The inspection related costs included in the above equation

fare $100,000 for the first unit and $80,000 for the

yecond unit)

Normal 06M Staff = 244

Security related staff = 56

Bu = 1,170,000

wie = 3570

cF = 0.75

Total O&M Cost = $24,496,330.

24,496,330 = 5.29 attas;

T70 x'8.76 x 0,75 ~ 719 BiLLs/kwhe

?The O&M cost levelized for the 35 years plant 1ife at 5% per

year u is

?Total O&M cost = (3.19)(1.81) = 5.77 mille/Kibr (levelized)

urs

---Page Break---

Total Coste:

Capital Charges 23.67 mills/Kuhe

Fuel Cost, 19.78 *

06 Cost sz"

35 years levelized cost %9.22 wille/Kvnr

(Start-up in 1985 & 86)

Tables 3.2.6 a, by and show the levelized costs for dif

ferent start-up yea

beyond 1985 at different escalation rates.

TABLE 3.2.60

LEVELIZED COSTS FOR A THO 6OOIMH UNIT LMR PLANT

ESCALATION SE PER YEAR (ALL COSTS IN MILLS/KWER)

1995	2000	260s	2010	205	2020
1499	95.0	22.16]	ass.sil	190.98]	a.0d

TABLE 3.2.60

LEVELIZED COSTS FOR A TWO 600% UNIT LMR PLANT.

BSCALATION 51 PER YEAR ALL COSTS EXCEPT URANIUM (U30g) at 7 1/42 PER

?YEAR IN MILLS/KWER

Istare-Up

rear 1985 _| 1990 | 1999 | 2000 | 2005 | 2010 | 2015 | 2020

10305 Cost

jc7.asaz esey| 2.08 | 35.72 | 22.31] 31.66] 04.92] 63.75 | 90-46 | 126.36

jorher Costs

(SE Ese.) 38.14 | 42.68 | 62.13] 79.29 | 102.20] 129.16] 164-84] 210.38

lrotat cose | 49.221 64.40! su.eu} s20.95| 246.121 192.931 255.30] 538.74

---Page Break---

TABLE 3.2.60

LLEVELIZED COSTS FOR A THO 6OOMY UNIT LAR PLANT. ESCALATION 7 1/42 PER YEAR

(ALL COSTS IN MILLS /KitiR)

Start-Up

Year x9e5_| 1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020

Jotai cost | 55.38 | 79.60 | 112.53] 158.27| 224.58] 318.69] 452.27] 6am

Figure 3.2.6 shows the plot of the sbove tables,

1-86

---Page Break---

FIGURE 3.2.6

30000, LEVELIZED COSTS FOR A TWO 6OOMW UNIT LMR PLANT

eee oars een

as vo 600'He Uaie Nuclear Plant

Plane Investoent Escalation 1978-86: 68/Ye,

aT Melon Bued Racatation 1985-867 5k, Uy0y 7 ae

08M Escalation 1978-65: 8x/vE~

Fie) = Interest Duriag Construction: ?92/tr,

+ Investnent Fixed Charge fate: 9/0656

Escalation Bates Beyond 1905:

Gurve F S2/fe, nt conte ware

7 SHE, ALi cote except 050g at 7 1/62

3-7 1/Ae/ie. all conte 278

TOTAL LEVELIZEO COSTS (mits kwh)

?a 1930 199520092005

?lant stare-lp Year ra

---Page Break---

3.3

3.3.1

OTL FIRED POWER PLANT

Capital Investuent Charges for Residual Oil Fired Plant

fopendix E illustrates the capital cost estimates of oi]

fixed pover plants. The following unit costs are estimated:

1985 Conte

Preval? 450 9

. 693.5 s/w

gert!* 1000 me

6968 s/w

+ Minimun indicated cost

EPRI costs vary between 694-8225/KW for 1000 we unite.

The following data is to be used in estinating the capital in-

vestment charges:

1, Unit Capital cost (1985) 693.5 s/ew

2. capital Investnent fixed

charge rate = 9.86362

Plant Capacity Factor = 1

Plant Cost Adders (K) o

Levelized plant capital cost in mills/kvh

(693.5) (.098636) = 10.4 milla/iwh.

75) (8-76)

rrr-88

---Page Break---

+2 Fuel of} Costs,

Between of], coal and nuclear fuel cost predictions, predicting fuel oil costs ie probably che most uncertain. The fast escalation of ofl costs is expected to continue at an

accelerated pace regardless of new findings of ofl reserves.

PREPA consultants?? have recently sade some predictions for the cost of residual ofl delivered at PREPA power plants. ?Table 3.3.28 sumarizes these predictions.

TABLE 3.3.20

RESIDUAL FUEL OTL COSTS PREPA

?CONSULTANTS PREDICTION

1980-1985 +1990 ~?~?«1998~~?2000

Delivered High 16.79 36.76 63.88 © 7.10 117.35,

$/38t, Medium 16,30 28.50 $0.40 69.18 91.48

(588) Low 12,59 24.29 40.08 53.36 71.47

?The Electric Power Research Institute (EP8r)!* predicts real low prices of residual fuel oil. Table 3.3.2b indicates EPRI predictions.

TABLE 3.3.20

RESIOUAL FUEL OTL COSTS EPRI PREDICTIONS

305% S

Delivered 011 1980 1985 «199019952000,

sper 3.08 3,133.23 3A 3.89

s/BaL* 18.24 18.78 19.38 20.46 21.54

equivalent at 6 MMBTU/BBL

11-89

---Page Break---

te

evident that EPRI has been underestinated . and that even the high values predicted by PREPA consultants are t00 low.

O41 cost today (mid 1979) is even higher than the predictions of

PREPA conoultants for 1980.

A curve fitting of the PREPA consultants "high'" predictions for

Residual Fuel Oil Costs indicates the following correlation:

Gy 08 + Sor (ay 3.3.2)

where

Cy = cose of residual off in dollars per barrel

Y= year less 1980

Coefficient of determination of fitr 2 = 1.0

PREPA consultants o{1 high price predictions are based on

a Linear yearly increase of approximately $5.03 per barrel.

The average yearly escalation rate for the high estimate in

Table 3.3.28 te 10.212,

?The fuel oil costs to be used in thi study will be based

fon a Linear equation similar co equation 3.3.2 but adjusted to the present oil market condition

Our cost equation i:

Cy = 25.00 + 6.s0v (ea. 3.3.28)

Equation 3.3.24 will be used up to the year 1985 only when the predicted price of fuel ofl is $57.50 per barrel, This corresponds to an average yearly escalation of 19% per year bet ?ween 1979 and 1985 vhich is well within recently experienced

values.

1-90

---Page Break---

3.3.22

Beyond the year 1985 an average escalation ra

of 9t per

year will be used in this study. Using this formulation, the

1995 predicted cost vill be $136.12 per barrel. The value ob-

tained using the Linear relation is §122.50 per barrel. After

the year 1995 the compounded escalation rate 9% per year predic

?tion is mich larger than the Linear relationship of equation

3.2.28. It ie reasonable to assume that after the year 1995

fuel oil costs will begin the real high spical of escalation

Aictaced by 4 9% compounded escalation as compared to a linear

relationship. Figure 3.3.2 illustrates the Linear and the com

Pounded escalation rates for the period of interest. Interest

of money has been taken as 92 per year, therefore the 9% com

Pounded escalation for ofl seems to be a reasonable assumption.

Levelized Fuel O11 Costs for a 450 mi O11 Fired Power Plant

For a 450 Mi of fired plant the folloving heat rate is

asouned:

Plant net heat rate at 75% load = 9200 Btu/kw he.

The heat content of a barrel of oil is taken as 6.0 million Btu.

?The fuel oil cost in mills/kw hr can be expressed at

O41 Cost aills/kwhe =

where L is the levelizing factor for the continuously

scalating

fuel price during the Lifetime of the plant (Appendix ®),

mrs.

---Page Break---

s00r

aso}

ooh

350

300h

130}

100}

al

ige0

Fig. 3.3.2

(ze

Predicted Fuel Ol! Cost

(1) ARTHUR 0 LITTLE PREDICTIONS {19701 FoR

(2) ACTUAL LATE 1970'S TREND

(iee10 (2-0) 9% / YEAR ESCALATION BEYOND 1968

190319901998 2000 2008 ?b010 ??zals

Yeor

urs

---Page Break---

Bg. ass

Cary? ?Usa ytor

andr sig

Tu

i, interest or cost of money = 9%

4, fuel escalation rate = 9x

at aR

a ee

= 3.3123

Of} Gost in mille/keh = 57.50, 9200 (3.31

103

= (68.16) (3.312)

= 292 mills/kwt

?The fuel costs in mélis/kvhr for various start-up years is

shown in Table 3.3. 2c.

TABLE 33.2 (c)

OIL FUEL COSTS IN MILLS/KWHR.

450 MW OIL PLANT

Start-Up Year	1985	1990	1995	2000	2005	2010	2015	2020
1st year cost	88.16	135.6	208.7	921.12	494.1	760.2	1169.7	1790.7
Levelized cost	292.0	449.3	691.3	10636	16365	2517.9	9874.1	5960.9

---Page Break---

3.3.3

Operation and Maintenance Costs

Operation and maintenance charges for ofl fired pover

Plants have increased considerably during the last decade.

Electrical World? reports 06M costs of the order of 1.0

mill/kw-hr for oil fired pover plants in their 20th. Stean

Station Cost survey.

PREPA experience with of] fired pover plants operation

is the best source for estimating 06M costs in this study.

?The Aguirre Steam Plant located in south Puerto Rico at

the Jobos Bay has two 450 YW steam turbo-generator units.

Total manpower for the two units is approximately 166 men

which yields 9

roximately 0.18 wen per MY. This figure

6

compares with Electes:

Worl? statistics

PREPA

hhas reported an 04M cost of 1.62 mills/kwh. for the Aguirre

Units 1-2 power plant for the wid 1977 to mid 1978 years

?The cost of OMM of oil fired plants ie a rather small

fraction of the total cost; less than 5 is reported by the

20th Stean Cost Survey of Electrical World, It is

sry to develop detailed equations to describe this

cost component.

In this study the average O&M cost of the PREPA Aguirre

Plant for 1977-78 will be taken as the early 1978 O&M cost

---Page Break---

for oil fired plants and will be escalated at the rate of 8% per year up to the year 1985 and St per year thereafter. Cost leve-Aisation during the plant Lifetine is made at 5t/year u and 9% per year i,

Table 3.3.3a illustrates the O&M costs for 2 450 M8 ofl plane.

TABLE 3.3.38

O&M COSTS FOR 450 MW OIL FIRED PLANT

MILLS/EHHR,

Inst. Year

cost

Levelized

cost

1965 1990 198520002005 2010 -~?«2015 2020

2.78 355 4.53 5.78 7.38 9.41 12,0015.30

5.03 6.42 8.20 10.46 13.35 17.08 21.75 27.76

3.3.4 Total operating Costs

?The total operating costs under the assumptions made are

shown in Table 3.3.4 and Figure 3.3.4 for plane start

indicated.

---Page Break---

forgv09 | srorse | strosz | ypreeot | a9's6ot | pycote | 66re9r | enrzoe reset +

geez sete "et sever 9v-or ore 9 co's 90

stoves | tense | srersz | svoeot | 9re0r crT69 e607 | oorzsz roe "ae

wees s6-y9 wesc | sex | ore vert | even ov'or cAur 1097

ee ~ ?? 90 + Teng

| Be Fook

oreret | crtart | area | eprtos eroze ecrere | stvect | 606 s381 Troy

est [over 6 sere ars ese see ae 90

?_}+-__? | +

|

coor | erestt | rose Ter) ate e807 srser | ovvea rong

-h 1 ?

Oe6E sir ?oree SOT ?0068 Sear Oe6T SET Fear Tg

aay sri

S109 ONLLVwEdO WLOL INVIA To ?lana

rere guava

? Py

1-96

---Page Break---

4sctie Fuel O41 Plane coat

Plant Investuent Escalation: Sz/Ye,

gc Eeatetone tite, PE

SR Prcatactons 1976-85, 85/ve; beyond 1985, says. .

Fixed Charge Rate on Investocats ?576ec63 i

TOTAL LEVELIZED COSTS (nits toh)

---Page Break---

3.3.5

Example of Total Generation Costs for a Two 450M Unit Oi1

Tired Tower Plast In Puerto Kite

In the eotination of levelized total generation costs for

?two 4S0MY of1 fired units, account aust be taken of the eco-

nomies that result from engineering, design and construction.

3.3.5.1 Capital Charges

Te is estimated that the per unit capital costs of # two unit 450

BW each oit fired pover plant is 90% of the single unit plant,

That i

Unit Capital Cost (1985) 624.15 s/w.

Levelized plant capital cost

in mills/Kvne 9.37 mitis/ime

3.3.5.2 Fuel costs

?The fuel costs in mills per k{lovatt-hour are as shown in

Table 3.3.2a with « 9X cost of money and a 92 fuel escalation

3.3.5.3 Operation and Maintenance

?The operation and maintenance costs are a2 shom on Table

3:3.3a with escalation rate of 8% per year before 1985 and St

Per year thereafter, Cost of money is assumed to be 9% per yea:

The total operating costs levelized for the 35 years lifetine of

?he two unit (450ave ea.) of] fired pl mt are presented in Table

3.3.5 and Figure 3.35,

1-98

---Page Break---

TABLE 335

LEVELIZED TOTAL OPERATING COSTS

FOR A TWO-UNIT (450MW ea.) OIL FIRED PLANT,

(Escalation at 5%/Yr. Fuel Oil at 9%/Ye.)

Start-Up Year 1985 1980-1995 2000-2005 «20102015 2020

Capital Charges 9.37 11.96 1526 19.48 2486 31.73 4050 51.69

Fuel Cost 2920 4493 691.3 1063.6 16365 25179 3874.1 59609

08M Cost 5.03 642820 10.46 1335 17.04 2475 27.76

TOTAL 90640 467.68 714.76 1093.54 1674.71 2566.67 3936.35 6040.35

11-99

---Page Break---

TOTAL LEVELIZED costs (wits /iwk)

?yo 490m Unie Fuet O81 Plant cout

?Blane tnvestaent Fscalations SEE,

Ruel O11 Escalation: 92/te,

O&M Escalation: 1976-65, 82/Ye; Beyond 1985, 58/te,

Fixed Charge Ra

Soe et

aes 1990, 1995

Plant Stact-up Year

---Page Break---

Gost Comparison of Conventional Alternatives for Flectrical Energy

Production in Puerto Rico.

The total generating costs for electrical energy production in

Puerto Rico have been estinated for coal, nuclear and fuel ofl altemetives.

?Te analysis includes the three cost categories of Capital Investeent, Fuel and Non-fuel Operation and Maintenance.

Jn order to present a fair cost comparison, the sane basic assuxp~ tious and economic parmeters for cost levelization have been utilized

except for particularities

ffecting each alternative fuel. Those factors

equelly affecting all the altematives heve been disre

wrded. The costs

for these alternatives are

vumarized and briefly discussed in this section.

Figures 3.4.1 through 3.4.4 present the total levelized generation

costs of the three altematives for one and twounit plants, as» function of start-up year, Two different escalation rates (namely 52/Yr. and 7 1/:2/te.)

have been used beyond 1985 vith exceptions taken for fuel-oil and Yellow

?cake hich are explained under Sections 3.3.2 and 3.2.3 respectively.

Nuclear plants chow the lovest evaluat

costs, followed by coal

aod fuel oft.

Te should be noted that eince Puerto Rico relies on isported fvel

for any of the three alternatives evaluated, this ites veights heavily on

the total costs, specially fuel ofl and coa

The necessity of new ses-port facilities for the coal altemative

adds additional costs to the capital investaent for the co plant which

hot necessary for the others.

mr-101

---Page Break---

Economies are realized if two unite are constructed at the sane

eite. These recult mainly from engineering, design, construction, man

?genent and non-fuel operation and uaintenance wit coat reductions.

Sone of the site facilities as well as operating and maintenance personnel

can be shared between the units.

11-102

---Page Break---

TOTAL LEVELIZED F575 (atts /kwh)

00 Fig. 3.41

Total Level ized Generation Costs of Power

Produced by:

free

1 600 me tuctear Unie

TA 600 save Nuclear Unit (UsQq ese. at 7 1/48/¥F.)

2? 450 owe Coal unit

3 450 me Fuel O11 Unie (Fuel OF1 ese. at 92/¥r-)

ANT costs escalated at 58/Yr. beyond 1985

trcept Vellow-Cake and Fuel Oi1 a5 Indicated in Curves I-A &

---Page Break---

TOTAL LEVELIZED --COSIS (mi2is/hwh)

600 ewe Muclear unit

4450 mee coal Unit

4350 me Fuel OT unit

(fuel 01" ese. at 32/¥r.)

ANI costs escalated at 7 1/4%/Yr. beyond

1985 except Fuel-O1l as Indicated.

Pane ?startup Year TIT-106

---Page Break---

TOTAL LEVELIZED COSIS (1 1Ls/kah)

ror rrey

Figs 3.4.3

Total Levelized Generation Costs of

Power Produced bye Two-Unit Plant,

Each Unit Rated as. Indicated:

1 600 me Muciear Units

Ia 600 ime Nuclear Unies (Up0y ese. at 7 1/42/¥F.)

2" 450 owe Coal Units

350 me Fuel Git Unies (Fuel 17 esc. at 98/¥r.)

AIL costs escalated at S8/Yr. beyond 1985

?except Yellow-Cake and Fuel Oi as

in Corves I-A 6 3.

gh gage HP

2000 2005 0

nr-105

---Page Break---

TOTAL LEVELIZED COSTS (mt115/4wh)

| Generation Costs of

Power Produces by a. Two-unit Plant,

Each Unit Rated as Indicated:

1 600 owe nuclear units

2450 me coal units

3-450 awe fuel of units

(fuel oi} ese. at 38/¥r.)

ANI costs escalated at 7 I/48/¥r. beyond 1985

except Fuel-0il, as indicated.

?Hane stacey Yaar?

---Page Break---

SECTION 4

LONG RANGE ALTERNATIVES FOR

ELECTRICAL ENERGY PRODUCTION

---Page Break---

40

Section 4

LONG aN

ALTERNATIVES FOR ENERGY PRODUCTION

?wsTRoDUCTION

tn order to adéress che energy situation in Puerto Rico, ran natives for elec-rical energy production

fom the Island regufre an economic evaluation.

Snecitic objectives are sot for caca alternative. Such objec~

ives include unit size, approximate date for the start of opera

and const

lon scherules. Unit costs are

Gotermined from the most recent and reliable eources. Totel creduction costs are determined and the sine at which the alterna~

lompete ecanomicatty with conventional sources is

for the Porte Rico scenario.

The ong range atternatives considered are:

1. otee
2. Mhotovoltaics
3. Bionane

4, Wing

?The logic in selecting and se=ting the long range scenarios

been based on the informat

generated from Research and Development programs being undertaken by CEER eince 1976 and on current availabie information.

ony experience and knowledge

A word of caution is necessary when making economic

evaluations and cost projections of nev developing technologi

While it is natural to expect lover costs as experience is deve-
oped in the manufacture of nore units (a learning curve
relationship), this in turn depenes upon the market demand which
sight be influenced by drastic changes. Normally, @ technological

---Page Break---

bal

breakthrough will lower the costs predicted by the usual Learning
curve and this will influence the market demand in a positive

Gircetion. On the other hand, environmental problens encountered, accompanied by stiff regulations and complicated licensing proredures, vill influence demand in the opposite direction.

Within the context of chis c!

writication, the economic evaluation of different long range electrical energy production alternatives is presented in the following sections.

OCEAN THERMAL ENERGY CONVERSION (OTEC)

This concept makes use of the temperature differenti

between deep sea waters (3000 ft) and surface waters to generate electrici- ty. Tt has the potentisl of meeting all of the electrical enersy

needs of Puerto Rico. Ocean based, or Floating type or lund based plants will have practic 'y no Anpact on land utilizat

Te is estimated than an OTEC-10 (4-10 ¥6 moduler, 40 Mi plant)

concept could be operational vithin 5 years. Economic calcula:

tions are performed for the 40% plant and for a 250 Mi! plant ?operational by 1985 and 1990 respectively. The 40 My denonstra~ tion plant is large enough to lend itself to an extrapolation to at least a five-fold scale in second generation of plants. The purpose of building a 40 Mie demonstration plant is to test the OTEC system vith full size modules and sufficiently large components in order co verify the cost estinates for the big scale commercial planes and thereby reduce the uncertainties

involved in the preliminary cont estimates and veri

?ying the

possibilities of future less expensive technical solutions.

?The economic evaluation follows.

wee

---Page Break---

4.1.1.1 Capital Tavestment charges

Several sources were exasined for capital investnent

cont estinates as presented in Appendix G, The most accur~

ate estimate for # 40 M¥e land based OTEC plant is chat

Prepared by Deep Oi1 Technology, Inc. for the specific site

of Punta Tuna, Puerto Rico?! This estimate gives an

installed cost of $5,230/kW (1980),

?The design conditions of an OTEC plant depend

nostly on the eite's oceanographical and meteorological

conditions, end these in turn affect the cost of the plant.

Ht is necessary to evaluate the construction cost for a

?specific site and to wake an optimum pouer system design

?adapted to the site conditions. In view of the wide range

of estimated unit costs presented in the literature and

their aforenentioned

ee dependency, we consider the above

mentioned unit cost of $5,230/Ki (1980) accurate enough

for the purpose of the present study.

One additional important consideration that must be

Addressed is the Life of the plant, The useful operating

Life of a demonstration project is usual

y shorter than

fone of @ proven technology. ?The Life of the OTEC plant

will depend mostly on the Life of the materials exposed

to the sea water environment and especially the effects

on the large sized heat exchangers.

experience exists with structures exposed to the sea

Since a large

water environment and since these have demonstrated long

Life, it ts logical to assume that OTEC plants will be

?economically operable for many years. For these reasons,

the econonic calculations will be done for 35 years of

operation, so that a fair economic comparison can be made

th the conventional alternatives.

3

---Page Break---

The capital snvsensor ?haeges are as Follows:

(60,000 KH) (95,2207

) = $209,200,000 (1980

doliars)

b. Yearly investnent Charges at 9t/yr. cost of

money ene 95 yonre apersting 1if

CRE = 0.094636

Tort FoR 0.08655?

(5209,200,90) (0.098635) = 20,636,651

e+ Yearly Enessy Production:

wise power © 23% (for 21°C 8 7 aves)?

factor #752

(49,090 «») (0.77) <0..75) (8760) = 202,356, 000Khr.

4, Tnvesteent Charges in milis/Kibr:

$20,524,651» 10° yor9; matte (sitar (1980)

i

06M costs of an OTEC plant cannot be too far

off an equivalent oi! plant.

The

rine portion, such as hull and other parts

and components exposed to sea water, will require more

maintenance, but tiese can probably be taken care of in

a larger tine cycle than the routine yearly naintenance.

?This can possibly be accomplished by soving the plant to

special shipyard facilities.

?The O&M costs will be figured on the basis of an assum

ed plant staff which will be correlated with total costs.

4

---Page Break---

?The folloving plant staff is ascune

1 superintendent

2 Asst. Superintendent

1 Adainistrative Supervisor

2 Secretaries

1 clerk.

5 Shift Engineers (1/shift)

10 Shift Operators (2/shife)

10 Pump-Turbine Operators (2/shife)

10 Condenser-Evaporator Operators (2/shift)

5 veility (/shite)

5 Security (1/shift) and personnel accountability

10 Boat operators (2/shife)

2 Karehouse Clerks

1 Purchaser-Whse. Sup

1 Chief Mechanical Engineer

1 Asst. Mechanical Engineer

6 Mechanics

Electrical Engineer

Fleetricians

Instrument Technicians

Chemical-Metallurgical Engineer

crenist

Assts. Technicians

Janitors

Painters-Drivers

Security (land, 1/shite)

4

1

1

1

2 Asot. Chemists

2

2

2

5

1 Janitor (lana)

Gardener (Land)

5 Shift Chauffeurs (1/shife)

106 Toeal

---Page Break---

Average annual staff cost per man $24,000 (1978)

Total staff cost: (104)($24,000) = $2,496,000.

?The ratio between staff cost and total O&M cost for

4 coal plant without FGD system as previously deter~

mined is 1.72. Assuming that the sane ratio applies

to the OTEC plant, ve have:

Total O&M cost = (1.72)($2,496,000) = $4,293,120,

?The cost in wills per kilowatt-hour {«

3

86,293,120 x 10° | ?

SSOP ei 7 21.22 milte/tme (1978)

The O6M cost in 1980 dollars with an 8% / yr

inflation is (21.22)(1.08)? = 24.75 milis/kuh.

AetLe3 To

Levelized costs

Since there are no fuel costs in this plant,

the total costs are composed of capital investment,

charges and O&M costs. In terms of 1980 dollars, the

total cost of the 40 Me Demonstration Plant is:

301.97 + 24.75 = 127 mitie/eWm

?The total levelized cost for operation in

1985 can be estimated by including escalation and

interest during construction, fixed charge rate and

leveling the 06M cost during the life of the plant.

Assuming 8% escalation per year, one year period

planning and contracting arrangenents, 2 years

design and 3 years construction, the interest during

construction and escalation factors can be computed in the following manner:

---Page Break---

Contracting

Commercial

Base Reference Year operation

rr |

???

Design { Construction

ais

3980

| |

1982 19e5

With @ straight Line cash flow of construction funds,

Bscalation before construction = (1.08)?

Escalation during construction = (1,08)!*>

Interest during construction = (1,08)!"9

Investment "scatation and

Interest during Construction ~

Toral factor = ar

OGY Eacalation at 8z/year from

1980 to 1985 ~ (1.08)5 = a7

Levelizing factor for 35 years life tine at 9% cost

of money in a Sz inflationary econony:

sa +y®

Tae

= 1.8L

where: r= sou

ie

Total Levelized Cost (1985)

Investwent Charges:

(201.97) (1.47)

= 0.038095

06M Cost:

(26.75(1.47) (1.81)

40 MWe OTEC Plant

Total Levelized Cost = 215.75 milts/Kvnr

(For start-up in 1985 and 35 years operation of the

plant)

qet

---Page Break---

250 Me OTE PI

If the results of the 40 Ye OTEC Deno Project are

stisfactory, the next reasonable step considered is

?the construction of a larger plant in the 250 ¥ range.

?Two factors directly affect the basic plant cost

(@ollars per kilowatt of installed capacity) of this

unit: one, the economies of ecale and the other, the

learning curve effect.

4.1.2.1 Seale Cost Relationship

?The effect of increased size upon costs for

large electrical equipment has been detersined by

experience to be in the form of an exponential reduct-

fon of cost in the range of 0.75 to 0.95 between small

ang bigger unit

f_ cam be defined as given by an equation of the

A unit capacity seale cost factor

following fora:

a"

f, = nie cost of big plane

cy unit cost of small plant

4

(es of the small size

where ¢, and G, are the capac

and bigger size units respectively and the exponent

than 0.75.

If the exponent E on the capacity scale cost equation

Eis lees than unit and usually not Les

given before is set at 0.95, the value of £, obtained

is 0.95,

For comparison purpos

im Section 3.1.4 for a coal plant will be exined,

|, the cost equation derived

mes

---Page Break---

?The coal plant cost equation C, = 795.95 "0+ 00002

gives the following result for the scale-cost factor

between 200 ~ 250 tite:

¢ 791000342 (250)

few 0.95

UOTE TT *

?This agrees with the previously estimated value

of f,. The cost in 1978 dollars of a 100 Mie OTEC

plant has been estinated st $3257/KW (see Appendix 6,

ref, 42). which extrapolated to 250 Ye gives

(52257 x 0.95) = $3,094 per KH, The total cost of a

250,000 K plant will be $773,500,000 (1978). The

effects of the learning curve are considered next.

4.1s2s2 Capital Cost Learning Curve Kelationship

?The Learning curve effect is a function of the

number of units produced, For this study, ve assume

we ORIN) gg

the following relationship: C, =

where: N= unit nunber

Gq * ave. unit cost of unit 8

cy = unit cost of unit number 1

K = constant factor independent of learning,

B= learning factor cost reduction

Te is reasoned that the accumulative average

production cost is reduced from the previous cost by

fa certain factor m every tine the number of units

produced on a comercial scale is doubled. General

Electric, for example, estinates that the production costs of large wind turbine generators can be reduced

to 90% of the previous cost every time the number of

units is doubled. propose a 97.5%

cost reduction for OTEC plants."* Due to the

Washon et. a

uncertainty in the learning rate estimates and the

manufacturing output, we consider 2 90% reduction to

be reasonable for the purpose of the present study.

---Page Break---

A aatket prediction must then be establised.

Jacobson and Manley froa MITRE Corporation predict three scenarios of OIEC market penatratica as a function

a

of economic incentives and development strategies.

?The three scenarios present total installed capacities

in the United States for the year 2020 of 2246 and

TL Cle respectively

Assuming © market development as depicted in the

lowest scenario and the cotal (22 GMe) been composed

of 250 Mie units, a toral of 88 unite by the year

2020 is predicted.

Rounding up the above figure to 90 units by the

year 2020, an S-shaped market curve for OTEC develop-

nent is projected as per Figure 4.1.2.

MARKET DEVELOPMENT PROJECTION FOR OTEC COMMERCTALIZATION

FIGURE 4.1.2

No. of 250 Mie

OTEC Unite

---Page Break---

TE the unit is to be operable by 1990, it must be order

83 (assuming seven years necessary lead tine)

ea duri

%

?therefore, no learning curve effect vill be considered

for this unit. The 1978 cost of the 250 YWe unit for

?operation in 1990 is $3,094/xW.

?The Capital Investment Charges are calculated for the

year 1990 based on the following:

Fer, = 0.098636

or = 158

?Aux. Power = 20%

Inflazion = 8£/yr, (from "78 to '85)

Stiyr. (from '85 to '90)

Capital Investment Charges =

34084) (0.098636) x (1.08)? x (1.0895

(9. 75) (0.080) (8. 76) 08) ance?

= 127 wits /eom

4.1.2.3 Operation and Maintenance Costs

?The operation and maintenance costs can be

computed a3 per the 40 Mie Deno Plant with a 20%

increase in staff, This staff increase is visualized

?as 20 additional shift personnel (4 per shift) for

Pusps-Condenser-Evaporator and T-G operation.

Sc = (124)(24,000) = $2,976,000.

The ratio between staff cost and total operation

and maintenance costs for a coal plant (without F6D)

is 1.72 (see Section 3.1.0.8)

?Total OsM Cost = ($2,976,000) (1.72) = $5,118,720.

?The total levelized cost in mills/KWh using the

previously defined parameters as in Section 4.1.2.2.

6M Cowt «($5,118,720 ca.08)?

Seay ta aay co wo 50,000)

(2,05)5(1.81) = 15.42 mitis/Kim

wet

---Page Break---

4.1.2.4 Total Petinaced Cost for 250 Yale OTEC Plant

The total cost levelized for the 35 years

operating Life of the plant with 1990 start-up base is thu

Total Cost = 127 + 15.42 = 142.42

For comparison purposes of the OTEC technology

with the conventional alternatives evaluated in Section

3, the costs of the 250 Mie OTEC plant are projected

rs beyond 1990 taking into

account the effects of the Learning curve and the

for future start-up v4

?economic escalation of costs, These are tabulated in

Table 4.1.2.4 below and graphically depicted in Figures

hele2eda and be

Te should be kept in mind that the Learning effect will become saturated after several units are

produced on a comercial scale. At this point, the

OTEC cost curves shown in Figures 4.1.2.4 a and b

Will becone straight Lines. Due to the uncertainties

involved in precisely estimating this occurrence, this

effect is not show in the curves.

rele

---Page Break---

Levelized Total Costs of 250 Me OTEC Plant in Puerto Rico.

? ie Year Indicated and 35 Years Operating Life.

TABLE 4.1.2.4

Interest During

Construction and Escalation Until 1985 at Bt/¥e and sh year or

7 2/8/ie thereartar,

Design and construction teed tiie 7 years.

Stace

2020

| SteeE-Up Year 1 1990 1995 | 2000 2005 | 2010 2015

Gansta coe (5/8) +

| M85 Dollars

sss | casoa! 0.552}

j Hl

3,945) 3,478] 3,197 | 2,927

cansta! teveotment | |

Gaersee (aitss/san) | i | '

£985 Doulas goose) seas) recs] sar) son] at.s9| ss

i H |

108) aa ne} ae as} ? ast aoe aoe

| tevetized ost conte 1 H |

Re oehlaen MAE) TE] ae ee, Tee ee} ee a

i |

set Extinaced Coe | | | |

| S/te. Escalation. !

| Bona we fa aw | aa | ae | am | as |

| i |

| T f

| oan snttaaea oon | |

| Ta3t/¥e. Bocalats

| beyond 1365, Tj 700) ase | ame | uae | ses | s6 |

qatar Pee epee

mwa

---Page Break---

Figs 6.1.2.408)

?otal Lavelized Generation Coste of Pover

Produced by: - -

Commie Huctear Unie

OOMe Nuclear Unit (Uy0p esc. at 7 2/42/Yr.)

2506 OTEC Unset

?s0esie Coat ast

??sonie Fuel O61 Uose (Fuel O42,

| A costa escalated at 52/tr.

beyond 1985 except Yellow Cake

{and Fuel Oi in Curves Ima

and 4 respectively.

st see 8 peepee en

{

reekr

ee

---Page Break---

Fig. 4.1.2.400)

000. « ?

?rtotel Levelized Generation Coste of Pover

'? Produced by:

a crotme Nuctear unit -

12) 2somfe omEe Plant

5. 50mm coat Plane

TOTAL LEVELLZED COSTS (wilte/4sh)

---Page Break---

Lavelized Total Coats of 250 Mie OTEC Plant in Puerto Rico.

Up in Year Indicated and 35 Years Operating Life.

7 salir therearter.

TABLE 4.1.2.4

Design aid construction lead t:%

Stare

Interest During

Construction and Escalation Untii 1985 at 81/Yr and sh year or me T years.

sary wear | vans | 2000 | 20 | zoio jas | amo

| | |

ee ee

| |

i ?

no | oats] ore] 0.656) oan} ose} sez

1985 Dollars | 5,303} 4,486] 3,905] 3,478} 3,197) 2,927] 2,768

{

i t t

| capttat tnvestnene | ! |

| Gideges fallin | | | |

1985 Dollars | 9952! seas! 74.03 65.27] 60.00) 34.95] 51.98

|

stn} ane} ans ae ast ae a

vevetland ott corte |

Settee Gist] are ea rere} ee iret ere} aaa

+ t

qn estimated oe] |

itr, taeglation |

Bm | ae | oan | oa | om | ae | am | os |

Total Estimated Cost i

Pista, gacalaci

| Rnd ed ws | 200 | a |e | ue | sos | om

wes

---Page Break---

42

WIND POWER SYSTEMS (UPS)

?The potential contribution of wind turbine generators (#16)

to the future electrical energy needs of Puerto Rico is evaluat (ed based on the report "Feasibility Study for the Use of Large

Windpower Generators in Puerto Rico",?? which is included in

its entirety as Appendix H. The cost

that report are placed under the sane bs

developed for the other alternativ

mates developed in

13 49 the estimates

to provide a consistent

analysis and a means of economic comparison.

?The power costs are calculated using the capital investment

costs, operation and maintenance costs

and the annual estimated

Power output. A construction period of three years is assuned

well as a plant Life of 35 years.

for the whole project

4.2.1 Capital tnvestment for Wes

The total capital investment charges for this project

im Puerto Rico for oper

follows (see Appendix 1)

icin in 1985 are calculated as

4.2.1.1 Plane cose

?The present estimated WTO's unit costs are §2.633

million and $1.91 million for 1500 xW and 500 KW units respectively. With a 90% learning curve and assuming a production of 100 units every 5 years, as indicated in Appendix M, the lowest evaluated average cost within the first 100 units vould be $1.31 million and $0.95 million,

respectively for the two unite.

The folloving itemized costs are taken from Appendix #. Twenty Five TG units are assumed to be located at one particular site.

weit

---Page Break---

TABLE 4.2.1.1

wes 1979 COSTS

ssw osMW

25 WT6's $32.75 x 10° $23.75 x 10"

Electrical Interconections (estimated 3.19 3.19

?Based on Bureau of Reclamation

?Studies app. 4.)

Design and Study (17%) en 458

Contingencies, site facilities, 539 4.08

supervision (15%) ?_

?Tota! Wind Power System $47.44 x 10° $35.56 x 10"

Cost (1979)

Weis

---Page Break---

The estinated Land requiceneats for this project

(Figure 7, Appendix #) are 2891 acres (2978 cuerdas)

?Two options are considered here. One is to buy the Lands

in this case the land cost will be part of the capital

vestment and subject to the fixed charge, but the

utility will have an asset appreciated in value at the

end of the useful Life of the facility. The other option

is to cent the Lands

part of the operating costs of the facility.

this case the rental cost will be

The estimated Land cost is:

2,978 cds. at $5,009 = $14,890,000

Tt should be noted

lat the Land use for both

?models is approximately the sane. The wind shadowing

effect, which determines the separation between unite

depends principally on the geometric characteristics

of the tover and rotor which are roughly equal in both

According to General Electric, the dianeters of

the rotors of the 1500 and $00 KW turbine generators

are 190 and 183 feet respectively.

4.2.1.3 Capital Tavestment Charges

Basic equation (see Appendix 5)

cece tg ETO) YD yt Ells /ev

* Wier Power ETO)

?The following parameters are used in the computa

Interest Rate

Fixed Charge ate (FC)

4 = 3 years

1 = 3 years

St/ye.

0.098636

---Page Break---

ly = 1.08

Tee = 1.09

a = 0.50

% + (ha) ¥ 45

a¥ eas

(2,08)4-5 = Late

(2.09)!-5 » La3e

Wind turbine power:

1.5) nominal = 288 kw net

0.5 M0 nominal = 236 kw net

Substituting the above paraneters in the Basic

Cost Equation, the following values are obtained

for 1985 operation:

TABLE 4.2.1.3

CAPITAL INVESTMENT CHARGES

Wing Power Systems (WPS) Copital investment Charges (enitis/kwhr)

ws and (Purchave option)

25-150KW (28kw net) Soe ?Say

?25-500KW (236 kw net) 109.20 45.73

ee

4.2.2 Operation and Maintenance Costs (0s)

The operating and maintenance costs have been estimated by General Electric (see Appendix i) to

be approximately 2% of the wind turbine-generator

cost, including electrical interconnections, site

facilities and contingencies. Tf the land is

rented, an annual rental charge will be included in

the operating costs. The rental cost is based on

---Page Break---

1a 108 of cost annual rental fee subject to escalation.

?To be consistent with the calculations performed for

the other alternatives, the O6M costs are escalated to

1985 at the rate of 8t per year and then levelized

for 35 years of plant Life, with inflation at 5% per

?The total levelized OSM charges in mills/kwh are

thus obtained by the following formul:

(eetimated 1979 coos) Lee) 022L

?detersined trom available wind

08M Cost

Where: L = levelizing Factor = (i)?= 1 | AUD" Ly gy

pork

rae" + Gs)

= 0.038095

Lye. ws Sige. e = Btlyr. Y= 6 years

ne 35 yes.

?The following results are obtained:

TABLE 4.2.2

LEVELIZED O&M COSTS

Wind Power System (WPS) 1d O&M Costs {mils/kwh)

WPS __Land(Rental Option)

25-1500KWI2.52x10" kwh per unit App.H) 37.6 os

?25-500KW (2.07x10° kwh per unitApp.H) 344 827

4.2.3 Wind Turbine System (WTS) Total Levelized Costs

?The total levelized costs for the 25 unit, central

station Wind Turbine System power plant, evaluated for

Puerto Rico, with a 35 year Life, deginning full

vee

---Page Break---

?operation in 1985, can be summarized from Tables 4.2.1

and 4,2.2 a8 follows:

TABLE 42.3

TOTAL LEVELIZED COSTS FOR WIND TURBINE SYSTEM

(25 Units, Central Station, for Operation in 1985

?at 8 Coastal Zone in Puerto Rico)

ee

wes Capital Investment 0am Total Power

(Charges(mills/K Wh) Chargestmills kWh) Cost mils KWh)

i

25-1500KW Unite

(Own Land Option 156.85 6 194.45

Rented Land Option 119.38 105.4 224.78

25-S00KW Units:

(Own Land Option 154.93 a4 189.33

Rented Land Option 108.20 an 226.30

The above results show that electricity generation

by central station wind turbine systems in Puerto Rico

is a competitive alternative to oil; however, it is an

expensive proposition when compared to other renewable alternatives. The extensive use of land resources and the Limited pover output are major contributors to the high expense.

?The differences in cost of power for the four ?options analyzed are not significant, but it is should bbe noted that no credit has been taken for the available land between units for other possible uses, nor

for land Value appreciation.

Other wind energy options are available for use in Puerto Rico, especially in the mid range and small range machines for distributed use around the Tsland, but their assessment ie considered out of the scope of the present work. Nevertheless, such viderpread

use of smaller units should be investigated,

---Page Break---

For purposes of comparison of the wind turbine generator altemative with che other alternatives evaluated in this study, the costs of the two lovest

evaluated options of 25 units central station power

pave are projected for future start-up years beyond

1985, takeing into account the lescning curve effects

?and the ecouomic escalation of costs. These are

tabulated in Tables 4.2.3 @ and b and graphically

Gepicted in Figures 4.2.3 a and b.

It should also be pointed out that energy storage

capacity can be provided to the WPS in order to have

4 continuous electric power output even at perieds

of low wind speeds. The wind alternative is only

economically viable as a fuel oil displacesent

alternative. Planning installation of wind turbines

for coal fuel éisptacement is an uneconomical propo-

---Page Break---

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6578 ?62 TERE Pes (unH/errs) s986I9

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vn)

TOTAL VEVELIZrD COSTS (ns

Pi rrrre

I

f

Fig. 8.2.33

Total Levelized Generation Costs

Total Levelized Generation Costs

of Power Produced by:

2600 Mie tctear Unit,

1A G00 Mie Miclear Unit

(Wog ese. at 7 174/ve.)

258 Five oTce unite

4850 Whe Coal Unit

450 Mie Fuel O31 Unit

(Fock Oy esc. at 8/Ye.)

5 25 Untt Nine Turbine Pomer

Park? (500 hea)

ALL costs escalates at S4/¥E. beyond

1985 except Yellow Cake and Fuel O11

in Gurves I-A and? respectively.

sopptet z eestsessy Pea

i oS

=i

TER wo dP Menace oF

ES

2000

Plant Start-Up Year

---Page Break---

TOTAL LEVELIZED COSTS. Caf 3/kah)

00

Fig. 4.2.30

fff

ALL costs escalated at 7 1/¢4/¥e.

except Fuel Oil which Ss escalated

sean.

bests

= Total Leveligea Goncration Costs

or Poner Produced by

6£0 Me thsctear Unt

250 tie UTEC Plant

450 wre Coal Plant

4850 tae Fuel O11 Plane

25 Unit Wind Turbine Poner

Park (300 XM a)

---Page Break---

STONASS FUELED DOWER PLANTS

Siowass fuel consists of dried or partially dried forage:

rasses oF cane, which provide combustible fiber that can be used as fuel in an industrial sceam boiler. Existing sugar

Pit! boilers provide an adequate example of boilers which use biomass in the form of sugar cane baggase co substitute for fuel ois bursing. Sugar mili boilers, hovever, are not di

for electric:

signed

?energy production but to produce steam

for the sugar anufacturing proc

?Their efficiency for

elecerfcat energy production is therefore, very iow. Sugar mill

boilers, however, offer probably the best facilities for deve

oping experimental pitot projects for the development of

aperonriate !arge scale techniques for biomass fuel burning,

hanclingy storage and transportation logistics. Such pilot prelecie could provide detailed technical J

a for He extrapole=

of large scale biomass fuel burning power plants on the level

300-500 se,

CORK Sas been heavity involved during the last three years

in the agricul

weal phase of biomass species selection, proving

ration, harvesting, sun drying and bailing of biomass.

Based on Figures on a BTU

6 have been detersined. Efforts are

We example of a 209 acre farm, co:

basis delivered for biom:

Presently being made by CEER to develop a pitt project in which the large scale Logistics of biomass ourning could be assesed for extrapolation to industrial type of electric pover plant boilers. Such a proposal has been submitted to the Government of Puerto Rico. ?®

?The ?state of the art" for this technology is practically ceveloped and is considered technically feasible. What is need=ed are boiler specification details and logistic considerations which are obtainable through the pilot project just mentioned.

It is reasonable therefore, to

differences between a coal fired power plant and biomass fueled power plant.

sume that there are no basic

---Page Break---

450 M4 Yiomass Power Plant

This plant is considered to be similar to a coal fired power plant as addressed in Section 3.1, vithout che requirenents of sea port facilities and FCD Systen. As such, the three cost couponents of Capital Investnent, Buel, and Operation and Maintenance coste will be addrese~ ea.

4.3.14] Capital tnvestnent charges

?The Basic Capital Investment Cost (Cy) of a

450 Mi coal fired power plant with an FGD system,

as detemined in Section 3.1.8.4, is $691/aee kw.

With an estimated 8% auxiliaries power requirenents

for coal plast with an FGDs;

S640.

?stem, the capital cost

por prose kilowatt is

?The FD Systen investment cost included in the

S100/KH (see Section 3.1.4.2). The

investment cost of a coal plant without FGD system

We (1978). Te will be

juned for the purpose of this Study that a bionass

fueled plant is no different cost wise from a coal

plant without FGD systen.

above figure

is, therefore, $540/gr0

Assuming that the biomass fueled plant will begin

commercial operation in 1985 and assuming that there

will be a straight Line cash flow of funds during a

five year construction time, the capital investnent

cost ist

(540) (1.08)"#?0-996) (1 ,09)-5)() 5 9951/ew (1985)

(See Sections 3.1.8.3 and 3.1.8.4 for details)

1.29

---Page Break---

With a Fixed Charge Rate of 0.099636, a Plant.

Capacity Factor of 75t (as for the coal plant), and

35 years of plant operasion, the capital investment

Cap. Investment Charges =

© 14,3 milte/iom

4.3.1.2 Biomass Fuel Costs

Biomass fuel costs have been evaluated in

Separate CEER studies under the Sionsss Program.

Figure 4.3.2.2 shows a flow

47 core studies b:

ran for the evalua

fod upon a

energy plantation have estinated

2 200 2

hyree!

Dionass fuel cost at $1.60/S9a"

2979). A three

stock assumed adds 4 cents/M#TU to the carrying

This cost is escalated at 8% per year untit

2985 and then levelized for 25 years of plant opera~

tion using the sane levelizing factor as vas used for

coal (See Sections 3.1.9.2 and 3.1.9.3), Table

4.3.1.2 (taken from the CEER Report) ?ilusteates the

breakdown of the indicated fuel price in 1979 dolla

With an assuned net heat rate of 10,000 BTU/Kim,*

the levelized fuet charges for the 35 years 1ifetime

of the plant vhich will being comercial operation

in 1985 is thu:

FL = (1.66)(10,000) (1.08)8(1.81)

1,000

L + (2601.81) = 47aitte/am

* A boiler designed for coal as primary fuel will have a higher heat +

when fired with biomass. A boiler designed to burn biomass as priaary

fue? will have Setter efficiency than a coal designed plant barning

dionass. The indicated heat rate needs co be increased depending on

the ease by approximately 515%

30

---Page Break---

FLOURE 4.3.1.2

BIOMASS FUEL COST FLOW DIAGRAM

EXPERIMENTAL

FARM

Lo

|

ane ied Fos) ou

for Teference Yese

Moot no + }

Wea

---Page Break---

TABLE 4.3.1.2

BIOMASS FUEL costs

PRELIMINARY COST ANALYSIS FOR SORDAN 7OA PRODUCTION

Land area 200 acres

Production Interval : 6 months

Sordan 70R Yield: 15 tons/Acre; Total 3,000 Tons of Oven-Dry Material

PRELIMINARY COST ANALYSIS

Lang Rental, at $50/Acre Year 5,000

2. Water (Overhead Irrigation), 360 Acre ft. 2,160

3. Seed, at 60 Lbs./Acre 4,800,

a. Fertitizer 10,000,

5) Besticiges 43000

6. Equipment Depreciation (6 mo.) 2,650

7. Equipment Naintenance (75t of Depreciation) 1,988

8. Equionent Operation (75% of Depreciation} 1988

5. Dieser Fuel 21200

10. Day Labor (90.00/day for 140 days) 12,600

IL Deltvery, at 6.00/Ton 18,000

Subtotal: 65,386

Plus 105 Error: 6,538

Total Cost: 71,924

Total Cost/Ton: (71,924 + 3,000): 23.97

Total Cost/Mil1ion BTUs (23.97 + 15): 1.59

---Page Break---

4.3.1.3 Biomass Pover Plant Operation & Maintenance

oi

?The O8M costs of the 450 MMe bionass pover

plant will be assuned to be equal to the 06M costs

of a sinilar coa fired power plant (as evaluated

in Section 3.1.10.6) without the FGD system. This

can be calculated by setting the sulfur content

(S) and the increnental total staff salary necessary

0 operate the FGD system equel to zero in the OM

cost equation. That ist

Total O&M Cost = (1.584) (TSC)+(4.9 x 107%) ckam) (0.80)+(1.43) (KW 433,660)

(1985)

(G4

= ($8,828,000)(1.08)7 = 15,130,000

with a 75% capacity factor and an 8% assused auxilia~

ries power, the levelized fuel cost is calculated

5 follows (using sane levelizing factor as for fuel):

08M Cost = __(15, 130,000) (1,000) <a

?TSS aBBy CS BESO: I5) TBO

= .5)01.81) = 10 witts/kw

1V-33

---Page Break---

4.3.14 Total Levelized Costs of a 450 tie Biona:

Power Pi

The total levelized costs during the 35 years

?asouned Lifetine of a 450 Mi biomass pover plant, at

4 75% capacity factor, a 92/yr. cost of money, and a

St/yr, Total escalation for cost levelization in fuel

and 06M is

Capital Charges : 14,3 mille/kwn

Fuel Cost + 47.0

8M cost, + 10.

yotal 71.3 milis/iom (1985 start-up)

Escalation of all the above costs at 5% per year,

beyond 1985, is shown in Table 4.3.1.6a

TABLE 43.1400)

LEVELIZED FOTAL COSTS FOR PLANT START-UP

IN YEAR INDICATED 5#/YEAR INFLATION BEYOND 1985,

eee

StartUp Year 1985 19901995 200020082010 «2015 ?-2020

TO 202070

Leveized Cost 71.9 91.0 116.1 148.2 189.2 241.6 2082 393.3.

(itts/K Wh)

eee

If an Anflation factor of 7 L/4R/yr. is used

deyond 1985 for fuel as well as OM, the levelizing

1-34

---Page Break---

factor is L = 2.508. The 1985 levelized cost changes

8 follows:

Capital Charges 14.3 mitls/Kuh

Fuel Cost 65.3

08M Cost, 1

?Totat 93.6 milts/ews (1985 start-up)

Table 4.3.1.45 indicates the total levelized costs

with 7 1/ét/yr inflation, for different start-up

years beyond 1985.

TABLE 43.1416)

LEVELIZED TOTAL COSTS FOR PLANT START-UP

IN YEAR INDICATED 7-1/4 /YR INFLATION BEYOND 1985

?StartUp Year 1985 1990 1995 2000 -2005-~?-2010~-2018~2020

Leveled Cost 934 132 1881 2669 378.7 5374 7625 1082.1

(crit KWH)

SS

From Figures 4.3.2a and b it can be ssen that

biomass fueled pian:

?are economically nore attract=

ive than coal plants. The required Research and

Development efforts to make possible comercializa~

tion of this alternative are deserihed in Reference

2

1ve35,

---Page Break---

TOTAL LEVELIZED COSTS fb Ls/eh)

Total Levelized Generation Costs

1_? of Power Proauced by!

600 "ie Nuclear inst

Y

IA 600 "Me Micleat Unit (0, ese.

BL Ser apse) ve

250 MWe UCC Unit

450 he Coal Unit

450 We fuer O12 Unset

ff

(Fuel O11, ess. at 94/¥r.)

5 25 anit Wind Turbine Power Park

(5009 a)

450 10 Bloracs Porer Plant

2% An costs escalated at 58/¥r~

beyond 1985 except Yellow Cake

and Fuel Oil in Curves "A

and 4 spectively.

72000" 2005

Plont-Srart-up Year

---Page Break---

TOFAL LEVLLILED COSTS (wi Lt /hsh)

Total Levelized Generation Costs

of Power Produced

?60 fhe Nuctear Vast

250 te OTE Plant

30 fre Coal Plant

430 he Pet Bal Pant

25.unte wine Turbine hover Park

{00 ya)

6830.08 sfonase Power Plant

Acs costs escalates ot'7 Wet)

Cccgpt Feel SHL which te eccalt

---Page Break---

[PHOTOVOLTAICS

The Photovoltaic process converts direct solar radiation

to electricity by using photoelectric cells. There is at

present a substantial world wide effort on research and develop-

ent to improve the viability of photovoltaic systens. Several

devil

eaploying different types of photovoltaic cells have

been proposed

Most photovoltaic cells are made up of crystalline seni-

conductors prepared in a fashion so as to produce the generation

of an electric current in an external circuit when the semiconductors are exposed to solar radiation.

Applications of electricity generation photovoltaic syste:

contral station

should be viewed in two different perspectives:

power ptan

and individual load center (ILC) generating

facitities, an

photovoltaic ger

rating facility is a suall

system installed at the point of electrical demand. Since there are periods in which the photovoltaic systems do not produce power, storage capacity can Se added or the system can be connected to the utility system to get back-up power. If these snail systens are collectively installed, they can contribute

fa substantial ansunt of the electrical supply in Puerto Rico

1h order to comercialize these systens, it is necessary to reach & point of economic competitiveness between the photo-voltaic systems and the commercially available alternatives.

Central station photovoltaic power plants will require large

land areas because the pover produced per unit area of solar ?5 emall. These plants will be owned and operated by electric utilities.

collector

The present study is directed to analyze central station types of power plants. For purposes of illustration and comparison, a 250 We photovoltaie installation in Puerto Rico is evaluated in the present study. This size vas selected because it is comparable to the size of power plant unit

requirements in the electric systen of Puerto Rico. Larger

---Page Break---

sizes will inpose severe restrictions on land resources. A 250 Mie plant will require 4000 acresof land.

4.4.1 Capital Investment of a 250 Mie Photovoltaic Power Plant

Tt is assumed that a 250 Mie photovoltaic power plant

can be installed in Puerto Rico for start-up in 1995, tn order for the plant to provide a continuous output, part of the energy produced by the photovoltaics plant during daylight tine (approx. 10 hrs.) will be delivered directly to the Load, and the balance of the energy generated during the sane daylight period will be stored for delivery during night hours (14 hrs). An economic load Gispatch program takes into account each unit connected to the grid and minimizes the total system fuel consumpt

ion. ALL units conpete with each other and are loaded

according to their increnental fuel cost. Since photo-

voltaic plants don't have any fuel cost and since their

output is only during daylight hours, they can probably

contribute substantially to improve the economic dispatch

of the overall system, However, such an analysis is rather

complex and has never been made or proposed. However,

it resenbl

the optimization of a hydrothermal systen

in which @ fictitious water cost y, is varied untit

snce is obtained with the scheduled hydro-enersy

use, Such studies will contribute considerably to the

{mization of storage capacity for photovoltaics.

Future CEER work could addrese this subject if funds can de secured, Some simple assumptions vere made in order to simplify the storage optimization problem.

?The hourly generation data of PREPA's power system for three consecutive months was analyzed. This shows that on the average, approximately 60% of the daily electric power generation is produced during the daylight

---Page Break---

period (7 A.M. to 7 P.M.) and 40% during the night. This period basically coincides with the photovoltaics product ion period, so that using this simplified criteria, 60%

of the photovoltaic plant generation will be dispatched on

4a load following schene during the daylight hours and 40% stored in a battery system for delivery during night time on a load following basis. This reduces the capital

investment and operating costs of the storage system.

Assuming an average of 10 hours of insolation and electric production per day, the charging rate of the storage system will be, on an average basis, 1.4 times its de!

very rate. This provides an emergency "spinning" reserve which is a function of the energy stored, The storage system can be discharged at the sane rate that

it is charged. Credit for the extra "spinning" reserve capacity can be calculated at the rate of capital cost of a conventional gas turbine, but no credit will be given in this study. Under this assumption 1 ky of plant capacity will have a storage capacity of .4 x 2ékvkr

per day cycle, or 9.6 kwh per ky of plant capacity.

To account for the absence of solar radiation during cloudy oF rainy days and storage system maintenance, a 292 additional energy storage capacity will be provided.

Present state of the art indicates solar cell efficien~

cies frow 6 to 25%. Ten percent efficient solar cells

are presently commercially available.

Solar array cosponent's efficiencies are assumed as follows:4®

Solar cells 10% efficient

Electric Battery storage 80% efficient

---Page Break---

Electric power conditioning equipment 95% efficient

?This gives a 9.5% efficiency for collection and product=

ion and 7.6% efficiency for the output of the storage systen.

CER has collected and analyzed solar insolation data

for extended periods of time in various locations through=

out Puerto Rico. The highest values have been encountered

along the southern part of the Island, vith the Ponce

station registering a yearly average insolation of

5.451 kevh/a?/day.

Using the above data, che area required to produce

26 kuhs in a 24h, period, with 60% directly delivered

to the load and 402 to the storage eysten, can be

computed as follows:

2%) (0.60 4

ST) (0-095

?The average insolation power per square meter is:

SL 6 0.227 Ku/a?

4.4141 Basic PI

ec

The cost of a photovoltaic installation can

be approxinated by the following relationshij

s $ array cost/s?

Plane cost 2; * (elant EF.) (insolation powerTe2)

+ Power Conditioning cost ($)_ + storage cost (8)

xe iw

The following values are assuned from the present day technology and an extrapolation of the

1-01

---Page Break---

a. Array Cost:

DOE Photovoltaic Program cost predictions are

shown in Figure 4.4.1°9°59, re is estimated

that by 1990 the cost of solar array modules

for large central station installations will

be \$0.15 - 0.40 per peak watt (1980 dollare).

Averaging this cost and considering that peak

pover is 1000 We/m?, we have:9!

Solar photovoltaic collector cell cost:

¥ 4,

tooo Me at loz eff. = 100

ze #

= $27.50/a2 (1980 dollars)

voo Ye x go.275

* P

Installation Cost:

Installation costs for wiring, structures, ete.

hhave been estimated by Schueler at $41.50 per

square meter.°° the total estimated array cost

is $69.00/n2 (1980 dollars). Array liferine

wumed to be 30 years.

Storage Cost:

In a vory comprehensive study of all solar

technologies, the Office of Technology Asses ent estinated cost projections for battery

storage for large industrial systems using

?advanced lead acid technology under develop-

ment by Westinghouse Electric Co./?

Battery Cost (proj. for 1990) $30.00/k¥n

neue

---Page Break---

AWoLSiM ONY $1¥09 a3Ide

Avuuy/21NGON MVEDOHE IWTOAOLONE 300

uvak uvONaTVD

05 68 99 10 98 ce ve ce ze 18 op GL wf LoL

TTT joro

_?? 4n- 3v95-nouwwnosnw

mENaNSOTIAO

emros'of|

sasvioung TWni2y

ABOTONN93L ANaWHND:

(3195 201110961) 4M/s AvauW/31NGON

---Page Break---

Installation, building and other costs

$05.7 = 0.7 268490) 16

where C is the capacity of the storage systen

in 1h.

That i

Storage Cost = 30.00 + (5.7-0.7 1ogyo1,200,000)

= 30.00 + 1.45 = §31.45/KWm (1980)

?The estimated Lifetime of the batteries is

10 years, which will necessitate two interim

replacements during the plant's operating

life,

The power conditioning systes (PCS) of a photovoltaic power systen includes suitable over conversion units, power switches for control of system configuration, and the wonitor and control unit. The PCS performs all the power conditioning and svitching required to Link system sources and sinks under the overall control of the sonitor and control unit. Coe projections of PCS iso estimated by the Office of follows:

?Technology Ass

PCS Cost (proj. for 1990) 40.00/10,

A Lifetime of 30 years is estimated.

Combining the above system component costs

we have:

Total Basic Plant Cost * 69.00 (0.60_ + 0.40) + (1.25) (31.45) (9.6)

0.227 (0.095 0-076)

+ 40,00

?Total Basic Plant Cost = 3520 + 377 + 40 = $3937/KH (1980)

rve44

---Page Break---

4.4.1.2 Total Plant cose

Since the Lifetine ot the plant is assumed to

be 30 years and the Life of the batteries is estinated

to be 10 years, two interim replacenents are projected

for the battery component.

?The equivalent capital cost (Ec) for a power plant with interim replacenents is calculated using

the following equation:

es mre + on; SRECEAR

where:

Bo

Bre =

cee

ra, act cue ns

see [ES J

1%

|

Set CE

YP y

cquivatent capital cost

capital cost of portion of a plant

unaffected by interim replacement

capital cost of the interim replace-

sent

CRE(r,N) = capital recovery factor for plant

where W ie the hook life of the

plant,

CR(z,LR)= capital recovery factor for the

ery

Fok

wr

LR

interim replacement where LR is

the interim replacenent book Life

+ fixed charge rate for the interia

replacenent

= fixed charge rate for the plant

= inflation rate

= discount rate or cost of money

+ number of replaceneats

= replacement Life

The fixed charge rate considered throughout

the present study for application to the Puerto

Rico Electric Power Authority has been the

rvab5,

---Page Break---

capital recovery factor plus a sualt aHlovance for

Sertoli each ws

equated to the capital recovery factor in the above

equation, thus obtaining:

Exe ext]

kes pce cri i +t 4

Pei, ae J

Substituting in the above equation with the usual,

values of {= 9z/ye. and @ = St/yr, we get:

Plant Unie Gost » $3560 + $377 |

W

= 3560 + 377 (2.18) = sus74/KW (1980)

The area requiced for the plane at 91 n?/KW Ss

BISI acres. An area of 4000 acres will be assumed

at $5,000 per acre vith @ total cost of $20,000,000

The total plant cost is th

Plant: (250,000) (4,374) = $1093.5 x 10°

Land : (4000)(5,900) = __20,0 x 108

Sa. x 105

4.4.1.3 Capital Investment Charges

?The scheduled and forced outage rate for

Hhotovoltaics must be lover than for an OTEC plant.

?Three weeks outage per year for photovoltaics is

more than adequate for forced and scheduled mainte-

nance, This yields 94% capacity factor, An 85%

capacity factor vould be more than adequate. The

investment charges for the plant for operation in

1995 are calculated using the folloving parancter:

---Page Break---

cr = 85

FOR = 0.101336 (30 years operating Life)

Fscalation (1950-1985) at 8z/yr.

Escalation (1985-1995) se S2/yr.

Thus:

Capital Tavestuent Charges =

1113.5 x 106) (0.101336) (1,08)5(1.05)10 =

(250,000) (8.76) (0.8

145 milte/Kwn (1995)

4.4.2 Operation & Maintenance Costs (06M)

06M costs vill be figured on the basie of an assuned

plant staff. The area per KH of plant power is 51m

therefore, for a 250 ¥¥ module an area of 3151 acres is

required. Such Large fare electronics and wiring will

undoubtedly require personnel. The following is assused.

Suggested staff for a 150 Mie Photovoltaic Pover Plant

1 Superineendent

Asse. Superintendents

Secretarie

Shift Supervisors

Shift Operators

Electrical Engineers

Electricians

Hlectronie Technicians

Instrument Engineer

Instrument Technicians

Mechanical Engineer

Mechanics

Clerks

Janitors

Gardeners and general landscapers

Security wen (4 Guards/3hife)

shift Chauffeurs

Chauffeur (regular hours)

UeiLity Men (general)

Chenical Engineers (storage system

dSslstane Cheatst ge syetes)

Warehouse (9

Warehouse Clerks

ae67

---Page Break---

2 Accountant

1 Purchaser, estinator

1 clerk

35 Toral

Ave. salary per man $24,000

Total salaries (24,000)(35) = $2,280,000

Assuming 6 factor of 1.0 for material replacement,

etc., (and this to be a very highly conservative

assumption since photovoltaice is a static system).

Year Total OM Cost $4,560,000

mills /KW = 4,560,000 = 2.45 mitt/ew (1978)

(230,000) (8760) (.85)

It should be aotea that the Lifetine of the

other alternatives analyzed in ehie study has been

assumed as 35 years. The Lifetine for

is assuned

plane

se no evidence has been

being 30 years ne

vowels Gants uae

pont tnd Shag nee A

tion is:

Levelized

Date cose) + (2-45) (1.08)7(1.05)!%c1.72) = 11. 76minas eu

6.4.3, Total Estimated

The total cost of the 250 MMe photovoltaic plant

Levelized for the 30 years operating life of che plane

with 1995 comerciat operation date is thus:

rete

---Page Break---

Total cost = 145 + 11.75 © 26.76 eiLLe/Kon,

For coupariso ovrpo:

logy with the othor alveraatives vvaluated in thie study,

3 of the photovoltaic techno=

the cost of the 250 ?Ke vhovovaliaic plant is projected

for future sturteu, years beyond 1995, Le should be

noted that se learning curve effects are considered

beyond this date,

Youruing curve will be satur~

ated by then as show) sn Figure 4.4.1.

It should aluo te sentivned that since photovoltaics

plants are modular in design, nactial electric output can

be obtained during the five vesr construction period which

in reality can be credited ta the overal) capital invest

?went, and which recucee

he scterect during construction.

?These have not been credited in orJer to have conservative

estinates.

Table 4.4.3.1 presents the plant's costs for commer

cial operation Seyond 2095, These resuits are graphical~

Ly depicted in Figures 4.4.3 a ane be

ri49

---Page Break---

TALE 4.4.3.1

?Total Levelized costs of a 250Mie Photovoltaics Plant ia

Puerto Rico, Interest During Construction and Escalation

Until 1985 at 82/Yr. Interest After 1985 at 9R/Ye. and

Escalation as Indicated, 30 Years Operating Life.

Start-up

Year 199520002005 201020152020

T

195.0 | 236.2 | a01.6 | 38,7 | ast.

Fcpicat tovestaene |

| charges (mitie/sah) 14s

| Levelized ou |

| Costs (ailZe/Run) us} isso | 2! ae | se] soe

5 Total Estimated | |

?cout (eilis/iimy =} 186.8 | 200.0 | 255.4 | 325.8 | 415.9 | 530.8

i I t |

capital Investment |

Charges (sills/#i) us | 208.8 | 292.0 | 424.3 | 587.9

Levelized 06M

Costs (nills/ew) | 15.66 | 22,2 | as | an.7 | 63.5

Escalation at

S| totat tatinated |

3 | Gowe Gettterniny sou | mano | ae | 90 | ane) aca

I

---Page Break---

Tora. LeveLizeo costs 1

coleres ef 9X/¥r. ond Yel

?For Electrical Energy Production in PR

restated et 314K 1 Ye

Gene in carve 2

PAKS

| wind aneray otrernotive (nthoot storage) shown ter comparative

Piont stort up Yeor

1.52

---Page Break---

LEVELIZED COSTS (mine / wn)

rorat

a

Fig. 4.4.30

Total Levelized Generation Costs of Alternorives

For Electrical Energy Production in PR.

1 Excolated of 7UA%/ Yr Except Fuel Ol which Ix

a # Wing eneray olrerative nithou storage) shown for comparative

1 purposes with Fuel O11 Cost component curve

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SECTION 5

SOCIO-ECONOMIC ANALYSIS

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Section 5

SOCTO-ECONOMIC ANALYSIS#

5-1 The Direct and Indirect tmpact of Oil Price Increases on Total

Costs of Puerto Rican Industrial Sectors an Input-Output Approach

5.1.1 Introduction

?The increase in oil prices by the Organization of Petroleum Exporting Countries (OPEC) since late 1973 has had profound impact on the economies of most nations of the world. The economy of the United States experienced a high rate of inflation followed by one of the most severe recessions in the Post-Kar period. Zeonomic capacity was reduced by four to five percent and the vreductivity of exiat

Yost studies of the impact of oil price increases have focus-od mainly on aggregate variables (gross national product, total Anvestment, general level of prices and others). Impacts on ntermediate and final demand and on cost the industrial sector have been, in most cases, neglected.

and price changes by

?The availability of input-output tables of the Puerto Rican

economy enable us to use input-output analysis to estinate the

direct and indirect impacts of oil price inereases sector by

?The purpose of this section is to estimate the inpact of oil

price changes on the cost structure of industries and on the produ-

cer's price index by the industrial sector. It will be assused

hat the increase in costs (intermediate inputs plus value added)

of the industrial sectors will be shifted forvard to the inter

ediate and final consumer. Inflationary impacts on producer's

sPrepared by Angel Luis Rufz, Ph.D. Associate Professor, Department of

Economies, College of Social Sciences, University of Puerto Rico, Ro

Piedras, Suerto #ico,

vel

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peices vini be measured. owewas

purchaser's prices can be also

escinated by vsing markenps of the industrial sector.

5

"means the iaport coe:

Methodology and Methazatiral Model

S.t+22 Methodology

we methodology and

price versicn of the Leoxting's input-output moder.

We model closely follow the

Prices ip the input-output syster are described by the

following e-ations:

2 ip the identify matrix

A ts the Seput-output coefficient matrix

(exclueino valve added)

V ip the ror vector of value adéed expressed in

dollars per unit of output.

cay

ef relative prices

The folloving is a detaited explanation of the nethodetogy and the node! used in our calcutations, The 53 by 53 total input-output transaction table in producer" peices for the fiscal yoar 1972 wan the starting point! wo industrial sectors shown in this table are Petroleu

Refining and Other Petroleum Products. The cox vectors

corresponéing to these industries show their sales to thea selves and co che other 51 sectors used ae intermediate

inputs in the production process. The latest available data show that the aver

fed about 7 tines from 1973 to 1979 (from approximately $3 per

price per barrel of crude has increas~

cients are included.

ve

---Page Break---

barrel in 1973 to $21.0 in 1979). This price increase has been

vuned

in costs of the industrial sector are shift-

ed coupletely to intermediate and final consumers. It has also

deen assumed that the price elasticity of demand is equal to

zero or is negligible for the period covered in this study,

used as 2 base for the calculations, and it has been

that the increas:

Since the total expenditures of an industrial sector

fare equal to its intermediate purchases or fron itself and

all other sectors intermediate inputs, plus paynents to

primary factors of production (value added), its tota? direct

cost vili ineres

in response to energy price increases.

?The change in costs will vary according to the share of the

sector's enerey inputs. Therefore, our first step vas to

16 the row vectors of intermediate sales of petroleum

wg and other petroleum products by seven t ine:

resulting increases in total expenditures (increases in costs)

were then divided by the total expenditur

Ga a

The

of the base year

8 case, fiscal year 1972), the year of our Latest

10 table to derive 2 1 by 53

prices. The second step (second iteration) was to pre-

multiply the price row by rov by the "new" transaction matrix

(with the inflated petroleum vectors) to obta:

expenditures, These latter were then divided by the vector

of total expenditures that vas obtained in the first step to

obtain a new set of price indexes. The iterative process

ft of scalars of producer's

new total

ce criterion. 4

continued unti? relative prices mat a convers

imited scope of this study prohibits entering into the analysis of ic changes in response to fucl substitutions due to price inereses. Sone models for analyzing energy impact have taken this latter fact into consiceration, See for instance, C.¥. Bullar, "An Input-Output Model for Bnergy Demand Analysis", Center for Advanced Compuration, University of Eilinois at Urbana~Chempaign, Urbana, [llinoie (Document No. 146, Dec. 2974).

---Page Break---

criterion used here was 0.01%. In other

words, every "round" generates a price index which is then

pre-multiplied by the different transaction matrices until

the process converges. In this case, the step by step

Process was not folloved since the iterative process was

shortened by using the Leontief?s inverse matrix.

5.1.2.2 The Mathematical Model

Definitions:

3. Po = set of 53 scalars each one equal to 1.0

in the base year, except for Petrolews

refining and other petroleus products

= is equal to a vector of total expendi-

tures for the base year (j= 1s asvy

3)

35 + 53 by 53 transaction matrix in producer's

prices (Valve of intustry : profection

feed as interaediate inputs by 5 induscey)

for base year (1972)-

+ value added in the ba

year (j= 4)

4

XP = value of production equal to intermediate

4 pur final sales for che base year

(2 1, Byer) 53)

Y= base year final demand (i = 1,2,..., 53)

ke Boe e

Lode Eek

a7 EP Oy?

k

2 pt = Baki

mi 3 a8 ,

v4

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where: 53 (aunber of industrial

sectors)

(number of iterations)

5.1.3 The Results

Bela

nase Year Daca

From 1973 to 1974 petroleum prices experienced

fourfold increase. From 1973 to 1979 price ineres

snounted to 700 percent, snd during fiscal year 1979, 50 Percent, This Section witl analyze the impact of these Price changes on total expenditures (costs) and on the Producer's price index. Mathematical proportions (constants) for each industrial sector will determine the inflationary impact of changes in petroleum prices of any magnitude. These Latter have been estimated for the 53 industrial sectors of the tnput-Output Table and for main Anustrial sectors, thus making it

Hier for the policy

fuaker to determine impacts without having to use additional

computer tine,

The Input-Output Table of 1972 (in its 53 by $3

dimension } includes two petroleum related sectors, The

first is Petroleun Refining and the second is Other

Petroleum Products. In the first exercise the price of

both has Seen oncreased seven tines (the increase of the

barrel of crude from 1973 to 1979) to determine the infla-

tionary impact on each sector of the economy. In the

v5

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second exercise only the Ferrolem Refining sector was

inflated, and other Petroleum Froducts renained constant.

Both exercises vere reveated, but ch

fold increase in petroleum prices (the inerease from

dis time wich a four-

1973 to 1974), and vith a 50 percent increase option

Gnflating both sectors by 10 percent) to give the reader

fan easy way to estinate inflationary inpacts of snall

Following is a detaites account of the

sults.

Table 5.1.) shows the base year figures of the

intermediate demand for petroleum sroducts used

pute

by 53 industrial sectors and supplied

Petroleum Refining

and Other Perroteur Products industries. Asco-#ing to the

a presented in

3962.7 eum products were deounced in our

economy. Of these, $491.9 ail?i

1g 1972 a eotat of

(ons were allocated to inter=

mediate denand and $70.8 millions were allocate: :0 consumer

denand. The Petreleun Refining industry supplied $433.7

?nillions (or 77.1 percent of the tota: of both industries),

while other petroleum produces supplied only $129.0 millions.

?The construction industry was responsible for 29.5 percent

demand, white the share of all

manufacturing sectors vas 36.5 percent, Within the eanufac~

of the tore: int

toring sector the petroleum industry's om consumption

accounted for 15.6 percent of the total. Within the service

sector the most important denands came from electricity,

trade and transportation.

Fach individual industry can be ranked according

to the share of inputs supplied by Petroloun Refining and

Other Fetroleun Products in the total costs of each

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Table sata

TWD FoR FUEL By IstuSTREAL SEcTOR

RHO ING FIStAn YEAR H99,

Desanding Sectors

Aagistuce

other Aeriectuce

Bethan

Sees

wee st

Fis

Rested Prats an Veeraies

Sauna Posi

Sensing

Sor 28 ectionay Pros

SOaST TRE raps

BONE! SP ect one

Bites Festi

os mites

Sees

Eeather"and tnathet Products

Stier Stone, Clay, and lass

wees

Fibleaced Srtat Promces

Sochinery tacapt Slecteieat

Bec:ticat sachinery

NiSechianeoue Manulactg cs

Gomticstions

Elecerieity

Haesice, Sawer and Gas

va

Finance

sree

Pessenat Services

BiSiners Services

eps senvdces

Biscrent wo Recreation

Seer nd Health Services

Groonsealts Coverment

Raveipal Goverseat

Fadeeal Govetocnt

Total tnterevtste tenant

corsueption

tee)

Seatvion Segters

Petroien

betrolon getroieam "tomes!

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industry. The proportions shown for mining, construction,

electricity and cement are the highest. For

27% of the total inputs used by Other Petroleum Products

supplied by the petroleum refining industry and by

seLf (but mostly by Petroleum Refining). In the case

of electricity, the share amounts to 15.6 percent, mostly

supplied by petroleum refining ($46.0 millions or 14.4

percent in base year 1972).

5.1.3.2 Change in Total Sxpenditur

?The input-output transaction table when read

columwise indicates that total expenditures by any industry

$ are equal to its intermediate inputs supplied by the

industries in the rows (i industries) plus the payments

to the "primary" factors of production in the form of wages

and salaries, rents, interest and profits (value added).

The two industr!

1 sectors supplying these inputs are

Petroleu Refining and Other Petroleum Products. These

industries Inport crude ofl from other countries and

refine it in Puerto Rico into products to be sold to the

53 sectors included in this analysis. Assuming that any

increase in the price of the crude oil will be shifted

Forward to the intermediate and final consumer and that the

relation between petroleum inputs to total inputs of each

sector remains constant (constant coefficients), the row vectors of the two industries supplying petroleum products

were inflated by the 700 percent increase in the barrel of

oil. Sy using an iterative proce

in the computer*

estimates vere made of the various "rounds" of increases in

grateful to the graduate student Loida Rivera for the many

hours she devoted to the programing and computer work. The Program

MOTHER (Matrix Operations That Help Economic Research) installed in our

conputer by Professor Eé Wolff fron New York University was used in our

v8

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total expenditures. Table 5.1.2 shows the results of the

iterative process for the first two rounds, the aggregate

Of the reneining rounds, and the final results after the

Process converged. Yor instance, an increase in the ave

rage price of the barrel of oil from $3.00 co approxinately

$21.00 fron 1973 co 1979, results in increased Federal

Governaent total expenditures from $239.0 mi

$496.7 mittion

(costs) which are incurred in providing its

final sales of services) at

increased producer's price (or Mill continue

Teasing prices

until the response to the shock has converged to a new set of equilibrium prices). Although tine periods cannot be attached to

whe different rounds of cost increases (or

ce index increase), we can determine with +he node!

approximate, ceteris paribus,* amount of expenditures and prices, In thie case the Federal Government's cost will increase until it reaches 107 percent

(using 1972 as a base year). Assuming the government will

ass the sane percentage of cost increase to the inteme- diate and final consumers, then its producer's price index will increase by the sane percentage (see Table 5.1.3).

Im Table 5.1.3 a producer's price index has been

constructed using the 1972, the year of the latest tnput~

output table, as a base Fiscal year, The table shova that

Af Petroleum Refining and Other Petroleum Products cost

have increased 7 tines as a result of price increases in

the barrel of crude, then the producer's price index for

each sector has increased or will keep increasing until

it reaches the percentage shown in the last coluan of the

table, For instance, the producer's price of cement will

increase 67 percent in the first round, 34 percent in the

?Wie are assusing zero price elasticity of denand for petroleum products,

and constant input-output technological coefficient.

---Page Break---

total expenditures. Table 5.1.2 shows the results of the

iterative process for the first two rounds, the aggregate of the renaining rounds, and the

wa? resuies after the

process ccaverged. For instanc

sn increase in the ave~

rage price of the barre! of ofl ?rom $3.09 to approxinately

$21.00 from 1973 to 1979, reeuite in

Covernsent total

nereased Federal

expenditures from §239.0

fons to

9494.7 ailiions (costs) which are incurred in providing its

services (intermediate plus final sales of services) at

increased producer's price (or Wil? continue J

easing prices

until the responce to the shock has converged to a nev set

of equilibrium prices). Although time perio?s cannot be

attached to the af:fere

rounds of co! eases (or

price index increase), we can determine with the node!

che approximate, ceteris paribus,* ancunt of énerease in

total expenditures and prices. In this case the Federal

Government's cost will increase until it reaches 107 percent

(using 1972 as a dase year). Assuming the government will

Pass the same percentage of cost increase to che interme

kate and final consumers, thon its producer's price index

WALL increase by the sane percentage (see Table 5.1.3).

In Table 5.1.3 a producer's price index has been

constructed using the 1972, the year of the ?atest

put

output table, as a base Fiscal year, The table shows thet

if Petroleum Refining and Other Petroleum Products cost have increased 7 tines as a result of price incr

price index for

ig unt

At reaches the percentage shown in the last column of the

the barrel of crude, then the producer

each sector has increased or will keep increas

table, For instance, the producer's price of cement will

increase 67 percent in the first round, 24 percent in the

?Wie are avsuning oro price elasticity of demand for petroleum products,

and constant input-output techaological coefficients.

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Table 5.1.2

RESULTS OF HTERATIAE POGESS SAENING ESTINATED NCES IN

THA, ENPADIT-HES 1S A USAT OF BEY Tes TSENGE

TUTE AVG ORE PER MAR Or Gee

Te tousand dollars}

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Terai Ghanges Ganges fds ALL

agents Inter eat Tee pots

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es oat em enes Maa Heed

a ARE ahh A GE igh

Sioa ee ie :

Presirved nutes and Vegetabtes

aces epee

Textiles sd ferarels

Pearse oad ces

and Niiseg Products

Pranting und Publishing

Retrochenical Frodeets

Bihet Comieat products

etrolece fining

Other Fetrotour Products

a

her Stone, Clay, & Class Prods,

Prlainy metas

Fabricated setat Prods.

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Transportation alent

instruments @ Related Prods,

isceltancous Mig. Undo.

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Other Services

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ESTOARD DOUASES DV nit rroDuce's peice marx

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Dairy Prod: iso

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Eta semen is Fe

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Fe cre oO GB OB

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second round, and 110 percent the renaining rounds (until

the process converges) fora total of 311.0 (adding 100 of

the base year).

Table 5.1.4 shows three éifferent scenarios of

Price increases of petroleum products with their correspond-

ing inflationary impacts, The three scenarios are:

1, A 400 percent increase in the barrel of off

corresponding to the period of 1973 to 19743

450 zercent increase in che average price of

Petroleum products from fiscal 1978 to 19790);

3. A simslation (for reader's convenience) of 10

percent increase in petroleum pric

Under the firet scenario a 400% increase in Petro~

teu Refining and Other Petroleum Product prices will increase

the producer's price index for each sector as shown in the

first colum. A weighted average for the whole economy will

result in about 77% increase in the producer's price index.

Tf it takes six years for the economy to accomodate such a tremendous increase in prices, the average per year change in the producer's price index would have been 10% (double digit inflation). If it takes 7 years, the average price incre:

#¢ would have been 8.5% per year. Both prices, being Producer's prices, do not include mark-ups

le by the industrial sector which are included in the trade sector. Historically, statistics on percentage price increases show lover results than the statistics from the input-output model. In other words, by taking only of] price increases a5 causes of the initial shock in the econosy and keep-

(@) The producer's price increase is equal to the difference between the figure shown in the last column of Table 3 and 100.0 percent. In the case of cesent, the increase was 211.0%, or 311,0-100.0.

(b) According to data supplied to the author by the Government Energy

vez

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Tabte Selet

(QWNE IN RONUEER'S aE INDEX BY HONSTRIAL secTOR

TW RESPONSE To TRG DUFF =v com Ge TS

?We Ice Fe a Cte

?Producer's Prices Change in fesponse to

merceag 50 erent 9 rercant plieative

Init er enue! tnae!) ?QE gE

dnt sector tenes! eee!? MOSSY MEU

se cr

SEE Tce

a

Son

Meat Products t

Sees :

Perel me ments

Grain Mla Prodocts '

Segara Confectionary Pro rar

eo wy

SOS Seve Ee

Boe Bette ma i

Rec Srr ae us

seoeee is

Katee eT aes Es

Ravan claret =

Rota St a

Recess ?3

CBSE cemicat reat

Petrotour tefinine

Other Petroleum Products

hbber 8 Pasties

esther and Leather Prods,

Cesene

Gther stone, Clay, (class Preds,

Feinery Seeias

eee tn re,

eee

Bea Sy

Geass a,

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pte

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gst, Sever and Gas

2ehsese

SSegSeigogtegsgenee 2

Medieat and Health Services 778

ier Sevice as

Gmmanvesl ty Government 8

anil Covemmone iw

Fedral toverent se

Visor

THISEerICaT price increase from 1875 to 1974,

2nistorical price sacrease during 19%,

---Page Break---

ing all other prices constant, a process of double digit

inflation will be introduced into the economy. As Table

5.1.6 shows @ S02 increase in of] prices will result in

9.59% increase in industrial costs (or producer's price index) using 1972 ae © Sase year and assuming the initial

shock came from the increas

Petroleum Refining and Other Petroleum Products, If the initial shock should cone only from Petroleun Refining sector then producer's price index for the whole econony should increase by 4.8% in response to a 50% increase in oil prices, Table 5.1.6 shows results for the Main industet

in costs of evo ofl sectors:

sector and for the whole econony. Table 5.1.5

shows the ranking of industrial sectors classified eccording to the inpact received, that is, increases in the cost of

produetion index which have been

sumed to be equal to

Producer's price index. The ten most inpacted sectors were

malt beverages, mining, electricity, cenent, transportation,

construction, alcoholic beverage, business services, other

stone, clay,

id glase products, and finance. This is only

4 partial Listing of affected industries since many

industries do not use fuel directly, but are affectee

indiree!

coment and construction industries vere hit hard by ofl

Price increases. For instance, the of} price increase of

by the sizeable amounts of electricity they use.

1973-74 was in great measure responsible for the severe recession suffered by the Puerto Rican econony from 1973 to 1976, Estimates offered elsewhere show that the los of employment in the construction industry was about 30,000 workers, which induced additional losses of about 16,000

workers in related areas®®, The inflationary inpact of any

change in oil prices can be determined by using constants shown in the last column of Table 5.1.4 and deriving equations like

?the ones shown in Table 5.1.7 for main industrial

Yor instances, Table 5.1.7 shows that if we increase Petroleum

vu

---Page Break---

Table 5.1.5

RANKING (FROM JOST AFFECTED TO LESS AFFECTED) OF INDUSTRIES

ACOORDING TD INRACIONARY DPACT, IN TERMS OF PRODUCER'S. PRICE INDEX,

OF 6 TDES INCREASE OF PETIOLEN PRICES FROM 1973 TO 1974

(0972 = 100)

?Transportation

Construction

Aleche'c Soverages

Business Services

ovser Stone, Clay and Glass Products

Finance

Trade

cellaneous Merufacturing Industries

Cthor Potroteum and oat Produc

Repair Services

?Transpor-ation Equipnent

Blectrica; Vackinery

Drug:

deve

ct, Sever and Cas

etcoioa Resining

Sogar sr? Confect onary Products

Sugar Cone

Batery Protucts

Machinery, Fxcept

Fersonal Sorvsees

Paper and Allied Prodacts

Manicipal Government

Bea Eetate

Princing and Publishing

Bottled and Canned So"! Drinks

Other Services

?isonet and Recreation

Cormnteations

Preserved Food md Vegetables

Petrochenical Products

Deity Products

Hoteis

Other Agriculture

Federal Goverment

Professional Instrinents

Furniture and hood Products

Otter Chenical Products,

Fabricate! Metal Products

hibber and Plascie Prodicts

Goororwealth Government

Grain Sill Products

Medical and Health Services

Miscellaneous Food Droducts

Sear Products

Leatrer ane Leather Products

Textile and Appare's

Tobaces Products

Pein Moe

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Table 5.1.7

EQUATIONS TO DETERMINE THE INFLATIONARY IMPACT

BY MAIN IXDUSTRIAL SECTOR OF OIL PRICE INCREASES

(1972 = 100)

Ghange Initiated in Petrolem

Refining Plus Other Petrolews Change Initiated in Petroteun

Products Sectors Refining Sector

Total Economy (weighted) Pj =aFpvo/5.2161 + 10 x 100 Py =aPy/10.4822 + 1.0 x 100

Agricutture Pi ?APryo/6-283 + 1.0 x 100 AP APy/12.613 + 1.0 x 100

Mining Py ?aM pg/2917 + 1.0.x 100 APs ?8PG/ 5.356 + 1.0 x 100 constriction PL AP yyg/S485 + 1.0.x 100 AP; tPy/ 5.988 + 1.0 x 100

Nanufscturing PL ?ah pso/S.7471 + 1.0 x 100 APs =4P,/12.9366 + 1.0 x 100

Preo/S431 41.0 x 100 a;

?comaisations Py ?AP pyo/5.983 41.0 100 ary

Pf 6.040 + 1.0 x 100

4.0 x 100

1.0 x 100

Py =aP,,,/3.008 + 1.0 x 100 aby

4 APrvg/4.098 + 1.0 x 100 aPj =aP,/ 9.537 + 1.0 x 100

Pi ?8Proo/4.9835 + 1.0 x 100 Py =aP_/ 8.7282 + 1.0 x 100

Preo/6-3680 + 1.0 x 100 Py =aP_/11.885 + 1.0 x 100

Renaining Service Sectors Pj = Pry/S.4117 + 1.0.x 100 AP =aP¢/12.2578 + 1.0 x 100

Cosmomea th Government

MP y49/7.2160 + 1.0 x 100

Pp/1T.327 + 1.0 x 100

Municipal Goverment Py ?AFrso/5.1470 + 1.0 x 100 AP; =8P,/ 9.736 + 1.0 x 100

Federal Government

~Pys/6.5420 + 1.0 x 100 AP; =APZ/11.824 + 1.0 x 100

Py = Producer's Price Index (1972 = 100) of the specific industry (or Total Foonoty).

Prag ~ Change in the prices of the Sectors Petroleun Refining Plus Other Petroleum Products

Goes 7.0, 4.0 or 0.50 or any other)

aR, = Change in the Price of Petroleum Refining (7.0, 4.0, 0.50 or any other)

Source: Estimation of the author.

---Page Break---

hetining Prices by 400: the rotucer's pre fades for the

tote economy vit inegenne y 138,94 Cor 38.342 ove bese

?This type of equation can Se derived for the 53

sectors by using last colum of Table 3.1.4.

5.1.4 Conclusion

?The purpose of this chapter has been to estimate the impact

of off price increases (using as proxy the increase in the price

per barrel of crue) in the cost structure of 53 industrial sectors

of ©

jerto Rican economy. Assuming that cose increases will be

edifted fomvard co intermediate and final consusers, 2 producer's

price index war estimated for

We industrial sectors. Input-ourpur

nodeling and accounting were used for the analysie. Tt was found

1d aeverly the economy of Puerto

that of price increases ?npac:

Rico. Coste increases to industries such as cenent, electricity

production, construction, mining, alcoholic beverages, transporta~

?sion, business services, and finance vere tremendous. Since

electricity costs are highly sensitive to ofl price increases,

industries with high electricity coefficients such as cement,
aqueducts and sewers and hotels vere severely impacted. Since 1960
spital and

energy intensive industries, and the competitive position of the

the strategy for economic development has focused on

island has been soverely hurt by recent developnents. the impli-
cations of this for the future prospect of the economy are very
serious, The results show that the indast
terns of output gener:
Job creation. ot only have hese Jatter two variables been
Increases, but also the general level of

price has been affected by the increases. The increase in the

1s most affected are

those that are sost important «

and

affected by of! 9

general level of prices also known as inflation will be the number

fone economic problem of the industrial countries of the Western

World, including Puerto Rico, for a long erm. This Study shows

---Page Break---

chat, Keeping all other prices constant, the increase in oil prices from 1973 to 1979 (assuming 2 conservative price of $21.0

Der barrel of crude in fiscal 1979) wilt induce, or has already

induced, ore than 130 in an estimated producer's price index,

net including surk-ups. This implies double digit inflation, even

when other prices are not increasing. Tr is vorth observing that

the price incre

?acexes such as those published by the Departzent of tutor of Puerto

Rico and the implicit price defletors of the Puerto aico Planning

higher than the historical price

Boned.

AS vas mentioned in the introduc

fon, oi price increases

were resnonsible in large part for the inflat?cr and the accompany-

5 foeses $3 gotual ourm

t emplcymant and ~stential outour in

uunteies in the vestern

dering che veriod of 1973 to

5. Eetinates show that the economy of Puerto Rico lost about

82,328.65

?Monsin output (intermediate plus final demané) and nearly 58,000 jobs (output at 3972 prices). These figures have

sexicus imp2icetions, If we remain dependent on imported oi for

our energy neeis, the economic stability of the Island vill

depend to # great extent on the oricing policies of OPEC. The

veader will have an idea of how ofl prices wil

affect costs of

Sedustuies and prices by examining some of the tables shown in this,

work.

After studying all the data shown here, one inportant con ion energes: Searching for altern:

urgent task which wil! require the atlocation of funds for

research and development. As the Krepp's Study specifies

ve energy sources is an

?there are a0 easy solutions to Puerto Rico's basic

energy problen. The nenr!y total reliance on inport=

ed petroieun compounded by its highly enclosed and

isolated system, and the existence of # large perrom

chemical infrastructure mean that rapic changes are

Bot possivie. Puerto Rico gust live with "igh energy

costs. Te cam, however, develop a strategy which

vas

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5.2

directs stronger efforts than at present tovard:

(1) developing now energy sources for che long run,

(2) greater conservation. "36

The topact_in Eeployment and Output of Two Alternative Rnergy

Source Projects: An Input-Output Approach

5.2.1 Introduction

As expressed in the Plan de Desarrollo Integral (Plan for

Integral Development) and in the Message of Governor Ronero

BarcelS to the Legislature of Puerto Rico, the search for alte

native sources of energy is a matter of high priority.°? The

?Island's dependence on imported ofl mikes it wlnerable to the

pete:

ig policies of the OPEC countries and introduces a great

to our open economy. According to the

recent U. $. Department of Commerce study of the Puerto Rican

economy? ?As long as Puerto Rico remains dependent on imported

cit for essentially all its energy needs, ite econonic

deal of instability

stability will depené

cantly on the pricing policies of

the oil supplying nations." *7 of1 price increases will continue

to have adverse impacts on costs, output, employsent, prices and

other macroeconomic variables of our economy.

Therefore, it is of strategic importance for our economic

welt

Hing to find alternative sources of energy. This process

will require the allocation of an increasing anount of resources

for research and development, for energy conservation programs,

and perhaps for a reorientation of the vhole strategy of economic

development. In the long run, however, most costs incurred in

developing alternative sources of energy vill be transformed in

benefits to our society. The benefits will be in terms of the

reduction of the dependency on imported oil, the decrease in the

deficit in trade with foreign countri

potential for job creation and output generation, and the reduet~

the increase in the

ion in the rate of growth of prices (inflation). These variables

v.20

---Page Break---

are the most common ones affects

by ofl price changes. However,

any project for the generation of energy vill require investments

in machinery, equipment and construction. The increase in invest

Bent will have an inportant multiplier effect on output, income

and enploynent. Therefore, in a cost-benefit analysis th

latter benefits mist be added to the ones most comonly analyzed

by econonis:

The purpose of chis section is to estinate the impact on

Production and employment of the investment needed to start two

Projects of alternative energy generation. These projects are Biomass and OTEC, and they are part of the alternatives being Studied by the Center Sor Energy and Environment Research (CEER) of the University of Puerto Rico (UPR).

5.2.2 Methodozogy and Model

An input-output model based on the 1972 input-output table Published by the Puerto Rico Planning Board had been used to

estinate these impacts.

In the case of Biomass, it is estimated that evo 300 My units as presently planned by PREPA will require about $350.0 illions in investment (1978 dollars) and an inerease of $67.0 nillion (1978 dollars) in agricultural production, and that it Will cause a reduction of $231.0 millions in petroleum import. () The OTEC project will require $773.0 millions in investment and will cause a $100.0 nition reduc o (1978 dollars). The impact on the economy of the increase in investwent resulting from the OTEC snd Biowase projects and the impact of the $67.0 millions increase in agricultural production of Biomass will be analyzed in this Section.

Son in petroleus inporte

(a) Based on information provided in Section 3.1.4

(b) Based on information orovided in Section 4.1.2

vee.

---Page Break---

?The Leoutief's oper nput-outp.ie model was used to estinate

Snvestment impact anc onployment.

deflated by © orice index wi

compatible with 1977

investment Sy supp

ree, investsent figures vere

2 as a base year (to make it

npuc-eutput table) Second, the total

ers was distributed according to weights

Serived from the investment vector of 1972 1-0 Table. After

obtaining the two vectors of

jestwent (one corresponding to

Biomass prosecé and the ether to the CTEC project), they were

post-multiplied by the eatrix of #irsct plus in ect requirenents

(ee 50 calle* Leontief's snverse ma

fx). The solution ve the

rodel is the output needed by all sectors of the economy to

?fy the demané fcr aféitional nvessaent gocts. Output

2 by emaiomment coefficients (wan per

tien dollars of output) to obtain the exployzen: necded to

To obtain output and employnent generated ty the increase of agriculture! activity, monetary figures were deflated by a

"? index with 1972 as Sese year; then che [-0 sodel was solved.

?The incruction of these two projects may have the follow

$9 impacts on the petroleum refining industry, and hence on the

economy of Puerto Rico:

1, If netroteum refiniery ieports are reduced, production

WILL be redvced, and enoioment and output well be

negatively a°fected.

2. Twports witl not be reduced because & Cecrease in

local sales will be offser by an increase in the

industry's exports.

3+ Imports and production of refineries (and other sectors

Of the econony) will be reduced. However, the deficit

Aaplicit price defiators for machinery ané equipment and construction

Published by Puerto Rice Planning Soard were ase.

---Page Break---

in che balance of trade will diminish,there will be

fa favorable effect that could be reflected in an

increase in the local components of final denand

(consunption, investment, government expenditures

and exports):

In the first case petroleum imports from the column vectors

of petroleum refineries? intermediate inputs in 1972 1-0 matrix

were reduced. Inports vere deflated to 1972 prices. It vas

assumed that industry production (internediate inputs plus value

added) vas reduced by an anount equal to the reduction in isports.

Ta addition, it was assumed chat

ince production of refineries

was reduced, sales to other sectors were also reduced (the row

vector of Sales) by the share of each sector's ofl inputs in their

ports was

the one published in 1979 Informe Económico al Gobernador (page 155) using 1972 as the base year.

total costs. The price deflator used to deft:

Im the second hypotheses we assume that the Biomass and

OTEC projects will reduce local sales of the petroleum refineries bur thar their external sales will offset the reduction, thus ?uaking it unnecessary to reduce imports and output of refineries and other industrial sectors. In this case exports were increased by the sane anount of reduction of local sales (using as proxy the amount of supposed reduction in imports of the first hypothesis). The exports vere multiplied by Leontief's inverse matrix to obtain output, and this latter factor was suleiplied

by the vector of exployment coefficients to obtain enploynent Figures.

Finally, in order to analyze the third case, petroleum refinery imports were reduced and the amount was allocated to domestic final demand. Once the vector of final denand was obtained, it vas post-multiplied by the inverse matrix to get ?output changes in the system.

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5.2.3 Analysis of the Results

5.2.3.1 Introduction

Table 5.2.1 shows how petroleum inport:

invest~

ment and agricultural production were affected by the introduction of two projects (Bioaass and OTEC) to serve

as alternative source of energy input.

Input-output analysis shows the iepact on eput

and employment in che system resulting {ron

10 changes

in the different variables (investment imports of petroleum

land agricultural demand).

TABLE 5.21

CHANGE IN INVESTMENT, PETROLEUM IMPORTS AND AGRICULTURAL PRODUCTION

?AS A RESULT OF THE INITIATION OF TWO ENERGY PROJECTS

(in Million Dollars)

Biomass OTEC.

(2:300mW) (1-250mw)

Increase in tovestment

In Curcent Prices $950.0 $730

At Constant Prices(1972=100) 2142 457.4

Reduction in Petroleum Refinzries imports

In Current Prices 210 100.0

?At Constant Prices(1972=100) 364 16.0

Increase in Agricultural Production

In Current Prices 670

At Constant Prices 450

---Page Break---

2. Production

Agelculeura!

Tabte 5.2.2 shows the impact of an increase in the denand for agricultural products by the different sectors of the econoay.

TABLE 5.22

?OUTPUT AND EMPLOYMENT GENERATED IN THE SYSTEM BY

?AN INCREASE IN DEMAND FOR AGRICULTURAL PRODUCTS

"Outovt in 3522:01181972-100)

Industral Sector Outpur® Employment

Agrieuitere 468 4208

ing and Construction 903 20

Wanutactering 7 231

?Transportation, Communications, and

Public Uvilities 30 185

Trace 26 240

Finance Insurance and Rea Estate 42 7

?Other Private Services end! Government 09 n

Required Imports 26 =

TOTAL na 5018

* Output is equal to intermediate sales plus final sales,

v.25

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Table 5.2.2 shows the following interesting facts:

4. For each million dollar increase in the demand

for agricultural products (especially used ae

wermediate inputs by ali sectors), product~

ion in the econoaic svsten wil! increase by

$1.6 millions. In cther words the output

multiplier will be 1.6

>, To produce this output it is necessary to import $9.6 millions.

c+ Direct plus indirect eaploynent generated amounts to 5,018 jobs, most of then in the agricultural? sector.

4, The rates of total employment created to employment created in agricultural is ecual to 1.19. This ratio is comonly kaown a8 employment multiplier type 1.

Baployment figures shown in Table 5.2.2 do not include employment induced by changes in consunption. By using @ ?closed? Leontief's input-output model, direct

and

\irect plus induced employment generated by agricul-

tural demand was obtaines. This latter amounts to 5,454

jobs.

smpect of Changes in Iovestmont

Table 5.2.3 shows the iapact on output and employment of

fan increase in investment needed to initiate the Biomass and OTEC

energy projects. The benefits in terms of production and employ

nent requirements are considerable. The increase in investment

resulting from the Bionass Project will induce an increase of

$392.4 million dollars in production in the different sector

To produce this output (given the level of productivity implied

in the labor coefficionts) 18,374 new jobs vill be required.

?The OTEG project will increase production by $843.7 millions, and

investment here means machinery, equipnent and construction in plant.

v.26

---Page Break---

Joyment requirements (@irect plus indirect) will agount to

39,338 Jobe. The increase in employment generated by the invest~

nent needed for the two projects will amount to nore than 57,712.

In other words for each million dollars of increase in investment,

output vill increase by $1.84 millions (output multiplier of

investaent desand) and exploynent will increase by 86.

TABLE 5.23

EMPLOYMENT AND OUTPUT GENERATED 8Y

INVESTMENT NEEDED TO STAST BIOMASS AND OTEC ENERGY PROJECTS.

(Figures in Mition DoMars, 1972100)

Biomass orec

?nitialfovestment (1972: 100) $ 242 Ss 4574

?u:put Generated in the System 3924 8437

Employment Creation 18374 39,338

Outpet oer Willion Dollars of

Investment Demand 1.84 184

Employman: per Million Dollars

of Investment Demand 86 86

What would the reduction in the unemployment rate have

been as a result of a 3671.6 million dollars increase in invest~

ment at constant prices? The latest figures for the unemployment

rate are those for the fiscal year 1979. During that year the

rate anounted to 17.5%. It is estinated that the increase in

investment resulting from Biomass and OTEC projects will reduce

the unemployment rate by 6.36 percent to 11,142.99

ver

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5.2.3.3 These Scenarios Rased on Petroleum Inports

Scenario One: petroleum imports reduction

will decrease output in industry and system.

Under this

of the Petroleum Refinery Sector vill be

scenario imported petroleum inputs

decreased by $231.0 millions in current dollars

(536.4 millions in 1972 do!lare) and by $100.0

millions ($16.0 millions at 1972 dollars) by

the establishment of the Biousss and the OTEC

Project respectively. It has been assuned

that the production of Petroleun Refinery

sector will be reduced and that this reduction

will have an impact according te each

industry's share of petroleum inputs in their

total cost of production, Table 5.2.4 shows

the results of this scenario.

?Table 5.2.4 shows that as a result of reduczion

in the output of the Petroleum Refinery Sector

tthe output of the systen will be reduced by 2

multiplier of 2.896. In other words, for each

million dollars of reduction in output of the

sector, the output of the system will

decrease by $2.9 million dollars (intermediate

plus final sales). Yor each million dollars of reduction in the output of the system,

?eaployment will decrease by 30 workers.

Love in output in this case will be much higher

than the loss in jobs because a large share of

the lo

which

in output is in the petroleum

2 capital intensive industry (enpioy-

ment per million dollar of output of thie

industry ie only 6.53).

v.28

---Page Break---

TABLE 524

REDUCTION IN DIRECT PLUS INDIRECT SALES

OF THE DIFFERENT SECTORS OF THE PUERTO RICAN ECONOMY

IN RESPONSE TO A REDUCTION IN ETROLEUM REFINERIES PRODUCTION"

{in Mitjion Dollers, 1972-100)

vndusts! Sector Biomass Project TEC Project

aL Sutput Emptoyment Output Employment

er 17) 85078.

Miring ane Const-ction 8st 438 288

Manutacturing e112 1528 35.66

Petro'aum Products 3927 256 17.28,

(Otver Manu?acturing 4185 1272 18.40

Trantcoration, Communications ané

Publie UvTites 727 38-3208

Trace 066 6802820

Finance, Insurance and Rea! Estate 205 «35 (0808

?Other Services Plus Government 609 58268248,

TOTAL (less ManufacturingJ0541 3,117 4643 1,370

---Page Break---

>. Second scenario: nomduction in petroleus refinery output; the reduction in local sales will be matched exactly by an increase ?in petroleun exports.

Under this scenario the total output of the econoay (including value added and imported inputs) will increase by a multiplier of 2.50. If imported inputs are excluded, the output multiplier will be reduced to 1.81. Local production will generate an out 1,000 jobs under the Biomass project and 431 jobs under the OTEC project. The payments to the factors of production (wages, sala and profits) will increase by $11.4 millions. ?This aconario {# the most probable one since, given the high level of deaand for petroleum products a reduction in local sales will be

8, rents, interests

offset by an increase in external

Table 5.2.5 shows the output and enploynent

impacts if the Bionase and OTEC projects are

introduced.

es.

Third Scenario: reduction in Petroleum Imports

will improve the Balance of Trade Deficit and

tthe improvement will be reflected in an increase

in domestic final denand.

Under this scenario final demand couponents

(domestic) vill increase as a result of improve-

ments in the balance of trade position of the

Toland. Table 5.2.6 shows employment and output

creation as a result of increases in the diffe

rent components of domestic final demand. As

---Page Break---

TABLE 525

EMPLOYMENT AND OUTPUT GAINS

INDUCED BY INCREASES IN EXPORTS OF PETROLEUM REFINERIES

(in Mion Dollars, 1972-100)

Industri! Sector Biomass Project OTEC Project

Ouiput_ Employment Output _ Employment

Agriculture on 10 008 .

Mining and Construction 097s 043 29

Manufacturing 4693470 2063 210

Petroleum Products 3369 (259 1745 3

Other Manufacturing 724 20 318 97

?Transportation, Communications, and

Publi Utilities 21498 094 43

Trade 227 8 1.00 103

Finance, Insurence and Real Estate 1.627 087 2

?other Services and Government or 68 032 20

TOTAL 5465 980 2403, aan

ess manufacturing)

Scoren: Extimates USM9 10 Model.

TABLE 525

EMPLOYMENT AND OUTPUT IMPACT

RESULTING FROM BALANCE OF TRAOE IMPROVEMENT.

(le Milion Dollars, 1982-100)

lndutrat Sector Biome Projet OTEC Project

Ouipur Employment Output Employment

?grcuture 132120 083) 48

Mining and Construction 520364 212 a

?Manufacturing 1925829 77 72

Petroleum Products 232018 0.93 6

Other Manufacturing 1683514 677208

?Transportation, Communication, and

Public Utilities 902417 361 167

Trade 6977 278 (287

Finance, Insurance and Real Estate 4.8085. 192 34

Other Services Pius Government 10.16 931 408 a2

TOTAL 5680 3.153 271262

Less manufacturing

?Source: Estimate using input output model

---Page Break---

explained before, these were induced by reduc-

tion in petroleum inports.

A glance at Tal

5.2.6 will show the follow

Ling facts:

i, The reduction in petroleum iaports result=

ing from the initiation of Biomass energy

Project will increase the final desand of

?the economy by the sane anount of the reduce

tion. The increase in final deaand will

increase output by $5.68 millions (output

pultiplier equ:

by 3,153. In other words each million

16 to 1.56 and employment

dollars of reduction in petroleum inports,

Af allocated to other components of final

denand, will increase output by §1.56

?million and exploynent by 87 jobs.

44, The total output generaced by the two

Projects witl amount to $79.5 niliions

and employment to 4,415 workers if petroleum

are reduced by $331.0 millions

(5231.0 miltions by Biomass ané $100

millions by OTEC) at current prices, or

$52.4 millions at 1972 prices.

Spores

5.2.4 Summary and Conclusions

?This section has cont:

ined some astimates of impacts on

exployment and output resulting from the initial establishment of
two energy projects, Biomass and OTEC. The folloving inports

been estimated:

Impact on the econony as a result of the initial

Anvestnent in machinery, equipment and construction.

vase

---Page Break---

tn the case of Bioaass the impact of the increase in

agricultural produc!

3. The impact of a decrease in imports (if any).

Im this Last case chree probable scenarios were considered:

a. A reduction of

sports will reduce production of petro-

oun refineries, and hence reduce their sales to other

sectors of the econowy.

b. Imports will not decrease as a result of the reduction in local sales; exports ¥i2t increase because of the

strong world denand for retrolew orode

The reduction in the belance of trade ¢ericit will

fina demand.

?The main findings derived from the analys's are the follow

ing:

1. Whea the Bionass project is introduced, agricultural

output will Snevease. This iner

wse will induce

further increa

of output and employment in the

syster: amounting to $71.8 million (in 1972 prices)

?and 5,018 Jobe created. Ta other words, for each

million dollars of increase in the demand for agricul-

tural produetion, output in

va will increase

by $1.6 millions axe exployment by 110 worker?

2, The invescment needed to establish the two projects

WiLL have 2 positive effect on the

scenony of Puerto

Rico. Both projects, if established at the ane

tine, will cause on increase in exploysest by about

58,000 workers, and the output of the system will,

increase by §1236.1, For each =

ition dollars of

1 tnerease by $1.84 millions

?and enploynent by 86.

ve

---Page Break---

3. TE the revuction ia che pecroteum imperte reduces

the output of the industxy, its sales te other

Sector will alse ve recuced. Im this case cho reduce

tion in imports wit) decraaze prodvetion én the

system by a multipticr of 2.869,

The probabilities are chat thers wil) be no reduction

im petroleum outpur i

focal seies ure reduced since

this

Moa do2lars of exports

the refineries can increase their exporta. 1

case, an increase of every

Will increase output by $1.56 million an employment by 17.

5+ The nost Likely vrobebiitey ie tat vie reduetie:

Smports and its favorable effect on the Sat

trade witl increase the components of domestic Final demand and this increase wilt have a positive effect fon output and enploymen:. 1 domestic final dewand is increased by the anount of the reduetion in petzoleun Amports, output will increase by $79.5 enployment by 4,415.

6. If we combine al! the po

ive effects with the first scenario (a reduction in output because of the Feduction in inports), the total e?fect of ¢

econony

will be that output vitl increase (on net basis) by

$1,156.15 millions and employment Sy 58,243.

7. Tf we assume that there will be ao reduction in petco-

?eum ouput, since the decrease in loca! sales are

offset by increases in its exports, then output will

increase by S1,386.6 millions and enployment by 64.141

workers

8. Finally, if ve assume that reduction in imports will

improve the balance of trade and this latter effect

---Page Break---

Wil increase domestic fins! demané, output wild

increase by 1357.0 nitions and euployment by 67,145

workers, If this is the case the unemployment rate, other things constants, coul? be reduced by about

7% from its 1979 levels.

The above findings show, without mich coube, chat the

introduction of the two enerey projects, Nicnass and OTEC will

hhave enormous benefits in terms of output ond eaploynent gonera~
tion given the availabitity of finance (wiwethe> 2 loans, local
savings or direct capital inports).

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APPENDIXES

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Genexal

coat is the most abundant fossil fuel found in nature. Within the United States, the most reliable source of supply for Puerto Rico, the coat resource (3.2 x 10! tons) is estimated at an eneray con~

tent of over 1000 years at the tots? energy consunption in the United

States at the 1970 level, The total of United States coal is approxi- nately 20% of the world total. There are large (unexpleited) coal resurces in Africe and South Anerica.

the Eactors Limiting the use of such abundant resource are (1)

ewizonsestal constraints on mining and combustion, (2) cool industry cevelopnent. and (3) transportation.

Costs are generally classified according to their carbon content and/or caterific values, Anthracites are the highest ranking coals with 867 fixed carbon and less than 8% volatile matter. Physically they arehard ané brittle, and they burn with a smokeless blue flame, They

are mainly used for donestic and industrial heating, for saking bri-

quel ovens, etc. Anthracites are generally unsuitable

9, for bak

for pulverized coal furnaces on account of their hard nature, Bitt~

ninous coals are classified as lov and sediu volatile coals because

they contain 16 to 31 nercent volatile matter and 69-56% Fixed carbon.

igh volatile bitusinous, subbituminous and lignite coals, which by

definition aust contain less than 69% fixed carbon, are classified

according £0 their calorific value as follows:

Bituminous 11,500-14,000 Beu/1»

subbituminous, '8,300-10,500 Btu/Lb

Lignizes = 8,300 Beu/Lb

tn the range of 10,500-11,500 Beu/2b, 2 coal can be considered bitumisous if it agglomerates upon heating; if it does not aggloner~

ate upon he:

Ling, &t is classified as subbituninous.

ma

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Figure A-I indicates the geographical locations of the various coal

reserves inthe United states 2°,/% Low sulfur coal is normally coal with 0.5% of less sulfur content. Goal coasts are very sensitive to the sul~ fur content. The fornation of gaseous SO, (and $0, to lesser extent) Guring coal burning presents serious health hazards. Present environnetal regulations practically mandate the use of wet scrubbers for most coal types.

Clean Ade Act

The Clean Aix Act, "Clean Air Act Amentnents of 1977, Public Law

operatic: of foss!? fuel

plants. Coat fired units required to adopt the "best available control

95-95", presents considerable restraints ct: 1

at least require scrubbers, electrostatic preci-

sntrolled Seiler combustion air/gas systems to control

fur in coal eccurs in three forms: organic, sulfate, and pyritic.

?ate sulfur compounds are soluble in water and can be renoved by wasii~ ing the coal. Pyrieie sulfur is the mineral pyrite. It can be separated by gravitational methods because of the high specific gravity differences

(5.0 for pyrite and 1.31.7 for coal). Organic suifur is an integral part

of

© coal matrix and can not be renoved by direct physical processes. tt comprises generally 30-70% of the total sulfur content in coal. The only known method to control the sulfur emissions in coal burning due to

the organic sulfur presence is by uashing the flue gases, 2 process called

Five Gas Deoulfuni

cn(EGD). The methods of removing sulfates and pyri=

cic sulfur by washing and by other physical processes is called coal bene=

ficistion. Coal beneficiation also reduces the ash content of coals.

Goal Cleaning

Coal beneficiation becomes important when transportation charges are

.gnificant. The beneficiation process can increase the BTU per Ib .

content, and hence can lower trangportation costs.

as

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Operation costs can also he reduced considerably through ash and

sulfur reduction. It is reasonable to consider coal deneticiation for

sed in ?Goal Pre~

aration for Combustion and Conversion? EPRI-AP-791, May 1978.

Puerto Rico. Details of coal beneficiation are disci

Table Al, taken from the EPRI report, indicates the six levels of beneficiation:

Level A signifies no preparation at all, Coals are shipped as ined, Run of Mine (ROM) Coa:

Level B indicates breaking only for size control to facilitate trans portation and handling.

Level ? is coarse cosl beneficiation in which the coarse particles are washed ang mixed with untreated finer particles segregated through

Lave! D represents a deliberate full beneficiation sinflar to Level

© but both the finer and coarser coal particies are washed.

Lavel & indicates an elaborate beneficiation process. Al! sizes

eed rushing to Liberate additional

amounts of ash and pyritic sulfur.

are washed sometines after rep

vel F represents full beneficiation. It uses level = beneficia-

tion to produce clean coal of the highest quality and also middlings of

average quazity.

?The ERT doucment reports that costs for levels C-D-E range in

the oréer of $.10 = .40 per ¥81TC), Any final consideration for coal

bencficiation levels will have to consider many factors entering inte the economical and environmental analysic.

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APPENDIX 8

[INTEREST DURING CONSTRUCTION AND INFLATION FORMULA

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INTEREST DURING CONSTRUCTION AND

(PLATION FORMULA

In treating the inflation and interest during construction costs

the following procedures will be used. Figure 3 represents the

flow of cash outlays for the project. Y, represents the number of

years between the date of the present estimate (early 1978) and the

beginning of construction. Yz is the actual construction tine, Y is

a of ¥; and Yp. The abscissa of the curve {s expressed in per

unit of conserve!

on time and the ordinate in per unit of cumulative

investment during construction. The area under curve ?e? is propor

sional to the time fraction during construction which represents the

accruing of inter

during construction. As an example suppose that

at a particular infinitesimal tine interval 4x between x-dx/2 and x +

Bx/2, an anount of money Az hae been spent, This amount of money (fe)

spent at tine x + 4x/2 must carry at least single interest equal to

(42) G-x) i, where i is che average yearly interest rate during cons-

truction. The value (4z)(1-x) represents the infinitesimal area shown

in the figure. If all these infinitesimal interest portions are added,

the net result is the area under the curve times i, This represents

the single interest o!

urge during construction.

Similarly (1-(2-42/2)) represents the anount of unspent money at

time (xitx/2) and (I-fetz/2)} tepresents the snount of unspent money at

tine x + 4x/2, Only the anount of unspent money can suffer inflation.

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?he average unspent fonds during the tine interval ax is [(1-(e-t/2)

+ Qo(282/20))/2 oF simply (1-2)/2,

?The average value (1-2) inflated for the saall period x gives an

infinitesimal inflation of (1-z)axig, where ig is the average single

wry yearly rate, ?en all these infinitesimals are added up, the

sum represents the single inflationary value during construction. Since

the curve of Figure B has been normalized, the area above the curve is

t-a). Figure 8 indicates the total and combined coupounded formula.

jeges for compounded interest rat

and inflation during cons

tion can be taken care of 4

equation in the following form:

F = (eet), THC

Dad (ty, 8%)

were

cost in S/kw

So = basic cost in $/kw for the base year (1978)

1 + years elapsed between

"¢ year (1978) and Seginning of cons-

eruction

Y, = construction tame in years

Te + 1+ ig, where 1p 19 the average inflation rate

?de 7 1+ ige where ige is the yearly average interest rate during

constewction

* = area under she normalized cumulative cash flow curve during

K = other costs exe!

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?APPENDIX B.

Interest During Construction ond Inflation Formulas

EXPENDITURES 5

i

a 13 ?yme~ *

Loy ve

STUDY ~~ GGNSTRUCTION

y+ yeors wicpsed between Cost estimete cnelysis end stort

viv coratrvetion Time in yeors

Or erce uncer normalized curve

(6c ave interest during construction, $i per yest

if intietion during construction, ave % per yecr

Simple interest corried on A® dollars spent ot time x.

= (az-K oe

ond (Rk) dB20 °

Simple inflotion en unspent dollors during AX time ot xy

HUB) AX Le ,

Total simple intiorion during construction =t Ye [ti-#)0 x ona [eta via

COMBINED INTEREST DURING CONSTR. AND INFLATION

COMPOUNDED = C1 4ig HOT Hye) OF arte

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APPENDIX ¢

GOAL PLANT CAPITAL INVESTMENT ESTIMATES

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< 1.2 Ahe/edilion 870

Particulate << 0.10 Ab /mittion wru

¥9, <_0.7 Ab/miltion Bru

Heat election systen

?Te atmosphere via wet cooling tover (cost adjustments to

ye made for special case of once through cooling $ neces sare)

Speciat preference will se given fo all references making cost

eatinates with new H°A NSPS standard considerations

Flue gas des

?urization (FGD) costs estimate to be included

for high sulfur coal (3% sulfur content)

02

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United Engineers 6 Constructors!

1232 vise Net Single Goal Fired Unit with FoD

Coal type: Situntnnous High Sulfur Eastern

Moisture (vt) 1.31%

Ash a6

sulfur (we) 3.2%

STU/Ib (as received) 11,026

Supercritical pressure, single reheat with pressurized

fumace

nx rating 9.775 ibe/he. x 10°

normal superheater outlet sau" "

normal zeheater outlet 7.486 "

Steam pressure, superheater outlet 3845 pois.

Steam pressure, reheater outlet 650 psig.

steam temp. superheater outlet 100° F

steam tomp. reheater outlet 000° F

fuel fiving rave 550 tons/tr.

Turbogenerator Cross-Compound, 8 Flow

Steam flow at H.P. turbine inlet 9.141 1b/m x 106

Steam press. at turbine inlet 3522 psia

steam temp. at #.P. turbine inlet 00°F

turbine back pressure(mulespress cond.) AUP ter

auxiliary pover 77 Yee

* Personal coummication (fromongoing revised costs studies)

cs

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Net station output 1232 we

Net Station heat rate 9238 Beu/kw he.

Mid 1976 Cost Estimate (UEEC 1232 Mue net) cont.

Ace. No. $103

20 Land and land rights 2,000

2 Structure and Tmprovenents 47,187

2 Boi'er plant equipsent 167,508

2 Turbine Plant Equipment 110,228

mu Electric Plant Equipment 93,523

25 ?Sec. Plane Equipment 857

25 Main Cond. Neat Re. syst. 15,850

2. Total Direct Costs 386,153

2 Construction Services 48,465,

2 Hone office Engr. and Services 17,000

2 Field office Engr. and Services _13,900

%. Total Indirect costs 79,345

Total Base 465,498

Costa:

Main Power Transt. 1,700

2. Omers cost including

consultants and site selection (ave) 34,500

3. Waste disposal equipnent and facilities

4. Spare ?:

res 2,700

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5. Fees and Permits 200.

Subtotal 67,100

Grané Subtotal 532,598

107 Contingency 53,260

Total 585,858

Unit Cost Estimate 385,858/1232 = $675.53/ew

Early 1978 Unit cost (1.08)1-5 (475.53) = $534/w

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United Engineers & Constructors +

194 Mut Wet Single Coal Fixed Unit with FoD

Goal Type Bituminous High Sulfur Eastern

Moisture (Zt) ase

Ash 1.6 z

Sutfur (% wet) 3.2%

Btu/lb, as received 11,026

Beiter + Supercritical pressure, single

reheat with balanced draft furnace

ax. rating 6.53 x 105b/ne

Norsa! superheater outlet S.81

Normal Reheater outlet 5.188

Stean Pressure, superheater outlet 3865 psig,

Stems Pressure reheater outlet 730

Steam teap.

superheater outlet 1010°F

reheater outlet 00°F

Yoel Firing Rate 365 tons/he.

?Turbogenerator Tanden-Compound-4 flow

Steanflow at HP turbine 5.81 x 10 1b/he

Steam press. at Turbine Inlet 3512 psia

Stean temp. at HP. turbine inlet 00°F

Turbine back pressure (multipress cond.) 1.7/2.5 in Bea.

*ersonal communication (from ongoing revised cost estinates)

6

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Turbine output 854 we

auxiliary power 60 ve

net sta.ourput 796 Uwe

net sta. heat rate 9682 beu/kw he.

id 1976 Cost Estimate (VESC 794 ?ve net)

Account No. $103

20 Land and land rights 2,000

2 Structures & Inprovenents 38,015

2 Boiler plant equipment 120,146

23 Turbine plant equipment 65,182

26 Electric plant equipment 28,931

25 Mise. plant equipment, 8,736

2 Main Cond. Heat Rej. Sys. 12,042

2 Total Direct Costs 275,082,

os Construction Services 35,218,

2 Home Engineering and Services 14,350

93 Field Office Engineer.& Services 10,628

Other Coste:

1

2

Total Indirect costs 60,195

?Total Base Cost 334,088

Main Pover Transf. 1,200

Omers Costs Including

Gonsultants,Site Selection ,ete.ave.) 25,575

Waste Disposal equipnent § facilities 20,500

c7

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4. Spare Parts 1,800

5. Fees and Permits 200,

Subtotal 49,275

Grené sub Totat 384,163,

10% Contingency 38,416

TOTAL 422,579

Unit Cost Estimate 422,579/794 = $532/kw

Early 1978 Unit Cost Estimate (1.08)1+5 x 532 = $597/xw ted Engineers § Constructors

Costs of FGD Systens

The foltowing costs have been determined from VESC recent estinates:

?Added Cost to Boiler Plant Equipment Account #22 ~ approximately

38-39% of account cost vithout POD,

2, Added Cost to Slectric Plant Equipment Account # 24 ~ approxinately

16-20% of account cost without FoD.

3. Indirect Costs ~ approximately 21% of above added costs.

4, Waste Disposal Equipment and Facilities - Increase by a factor

of 2 over plart without FoD.

?The tots FCD system added costs included in the estimates given here

1232 Ms (gross) unite (mid 1976 costs)

S6L/gr088 kw

oF $64.8/net ker

854 Me (gross) unite (mid 1976 costs)

§71.A/gross Kw

$76.5/net tow

cs

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PREPA Engineers and Consultants datak

450 Mv Grose Coal Plant

Coal Type: Bituminous High Sulfur Eastern

Moisture (Z vt) aa

ash net

Sulfur (2 we. wet) 3H

BTU/A (as received) 11,000 seu/1.

Boiler : 2800 psig pressure, single reheat vith balanced

Grate? furmace

ax ratings

normal superheater outlet

Formal reheater outlet

Steam pressure, cuperheater outlet

reheater outlet

Stean Temp,

superheater outlet

Feheater outlet

Rate

Turbogenerator (Tc4P-26")

Stean Flow at H. P. Turbine

Steam Press at Turbine Inlet

?Steam Temp. at H. P. inlet

Turbine Back Press

1010°F

1000°F

200 tons/iiR.

Tandea-Compound 4 Flow

Hitachi Turbine-Gen,

2400 peig

1000°F

2.5" Hg A.

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Auxiliary Pover

Net sta

Net Sta. Heat Rate

36 Mere

414 Me

9800 Btu/Kw HR.

2%

25

26

1

92

93

? Land and land rights

Oe) secures 6 trove

Qi) Boiler Plant Equipment (1)

OO Nt.

(5) acntny tae, pen

O19 siscs Your Fane Ei

Main Cond. Heat Rej. Sys.

Gnet. in? 314)

Total Direct Cos

justed

vunad~

Adjustments

) itaent TH6

(2) Fop System for 3% Sulfurcoal

?additional cost

Total Direct Cost, Adjusted

Construction Services (132)

Home Engineering Services (6%)

Field Office Engineering Services (4%)

Total Base Cost

cost. $103

16,520

314,220

6,700

6,030

no

166,180

25,000

32,000

381,180

23,500

10,900

7,250

222,830

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Other Costs

2) Main Power Trans£. (FEC #353) 720

2) Owmers cost including Consultants, Site

Selection, ete. (82) 17,800

3) Waste Disposal equipment and facilities (62) 13,400

4) Spare Parts (1/22) 2,228

5) Fees and Pernits 200

Sedtotat 256,528

10% Corsingency 25,652

Torat cost 282,180

ait Cost 282,180/414 = $682/kw.

conn

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2nd. Estimate

PREPA Consultants Estimate for

50 My Coal Plane ®

PPC Ace.

au Structures and Improvements

31 Boiler Plant Equipment

aus 16 (and cooting system)

3 Accessory Electrical Equipsent

318 Mac. Pover Plant Equipment

383 Main Power Transt.

Total Direct cost

Zaéirect Construction Expense

Ocean Freight, Litherage and Trucking

Engineering Design and Construction Management

Subtotal, Direct and Indirect cost

Contingency

Total (PRURA consultants)

Adjustments

Turbine Generator in Storage by ower not

included in above estinate

Total Costs

2- Additional FED system for changing from Western

fo Eastern (High Sulfur) coal (PRIRA consulant

16,520

114,220

6,700

6,030

no

0

144,900

35,000

6,000

17,000

202,900

41,100

264,000

25,000

12,000

$281,000

---Page Break---

EPRI Cost Estimate

1000 147 Kee

Coal Type.

Boiler

Max rating

Biante

Bituminous High Sulfur Southeastern

(Central Appalachia)

Moisture (we) 8.2

Ash (2 we) 8.2

Salfur (2 vt) 304

Btu/Ib. 12,130

2800 psig single reheat with balanced

erate

Normal superheater outlet flow

Steam tenperature, superheater outtet 1000"F

reheater outlet aoory

Fuel Firing Rate

Turbogenerator Tanden Compound 6 flow

Stean flow

Steam Pressure at Turbine inlet 2400 psig

Steam Temperature at H.P. Turbine 1000°F

Turbine Back Press

Turbine output

Auxiliary Pover

Net Sta output 1000 6

Net Sta. Heat Rate 9850 Btu/ieeh

* EPRI P5-866-8R Special Report ~ June 1978

o3

---Page Break---

EPRI Cost Estimate 1000 MVE Goal Plant (Continuation)

(Bechtel Enginners Consultants)

No Breakdown given

Lowest Cost Reported (Table XII-A) fe for Southeast region with

$550/kw for 2 unit installation,

For one unit installation it is indicated in EPRI reference to divide

by .96 the tuo unit cost estinate.

Plant cost estimate includes common Des

sn Criteria (1976 NSPS - EPA)

End of 1977 (or early 1978) cost estimate 550 + .96 or $573/kw

Coste of FD Systens

Tncluted in above cost is the FCD System estimated at $105.00/ku

Values for the FOD system ranges from $85 ~ 155/kw.

---Page Break---

Gibbs and HALL

(Paul de Rienzo)

1130 ME Net Coal Plant Estinate*

coal Type: Bituminous High Sulfur Eastern

Moisture (wt 2) 5

Ash (2) 10

sulfur 25

Beu/Ib (as received) 12,500

Botte:

Max Rating

Suverheater Outiet

eater Outlet

Stear Pressure : Superheater Out

reheater out

Steer Temp., superheater ovt

Feheater out

Fuel Firing Rate

Turbogenerato

Steam flow 4.7. Turbine

Steam Press. Turbine outiet

Steam Teap H.P, turbine

Turbine Back Press.

Turbine ourput

Auxiliary Power

Net se

output 1150 26

Net Sta Heat Rate 9600 Beu/ewh

68

* The Outlook for Coal and Nuclear Power ~ De Rienzo

ERS*TUIS "NIB AEESGNAL Agegcsanign af feergloge Investnent Analysts at

ens

---Page Break---

Gibbs & HELL

(Paul de Rienzo)

2-1150 Mye Coal Plant Cost Estimate

1978 Plant Costs

cost for:

Site Preparation

Maverials

Equipment

Structures

Instellation

Total Base Cost $/Ki 328.0

cost for:

Installed Flue Gas Desulfurization

Studge Disposal Systems

Total Costs $/xW 80.0

Conts for:

Indirect Expenses

Engineering

Construction Management

Contingencies

Total Costs $/kw 87.0

Grand total Cost 495.00

SE added for of

unit installation

(495)

C94) 3526 aw

co6

---Page Break---

Dravo Cogene!

?and Gibbs:

Eetinate for a 20 Mie

1978 Capieat

Coal type Unspecified

Boiler Unspecified

Turbogenerator unspecified

fant Net Outpue 20 ave

capi

Cost (1978) + S800/ew

?Aseuses plant seets comon design criteria for coal plants (EPA, criteria and wet cooling tovers).

"fons in the Design and Engineering of Cogeneration

Facilities R.e.Kropp, E. J, Hansen, and R. Destefani

ration Company and Gibbs § Hill, Inc.,

Dave Cogene-

March 1979 ASME Conference.

---Page Break---

APRENOIX D

---Page Break---

20

2

2

23

ery

25

5

NEW 585 MW Not Nuclear Estimate (1

?Total Direct Cost Data Sourc:

PREPA Consultants

Engineering Services, Construction Management and

Other Indirect Data Source: UEC

(1978 dollars)

(320) Land and Land rights

(21) Structure and Inprovenents

(322) Reactor Plane Equipment

(923) Turbine Plant Equipment

(324) Electric Plant Equipment

(325) Miscellaneous Plant Equipment

Main Cond. Heat Rej. Systea

Gnetude in 323)

TOTAL DIRECT cost

Construction Services

(36.72)

Hone Engineering Services

aL

Field Office Engineering

Services (6.82)

?TOTAL BASE COST

Other Costs:

(Q) ain Power Transformer

(2) Omers Cost including consultants

site selection, etc. (8.62)

(3) Additional vaste disposal facilities

43)

) Spare Parts (.62)

(9) Fees and »

sustotaL

GRAN SUBTOTAL

10% Contingency

TOTAL

1978 Unie coms

S775 /08

be

$103

3,000

73,900

3243450

52,100

18,400

2,000

3,80

45,733,

32,061

18,621

So ,205

1,500

31,841

5,183

2,221

1,400

8153629

---Page Break---

New 585 Mi Net Nuclear Plant Estimate #2

Data Source: ALL by PREPA Cont

1978 dollars

ace (rca) $10?

20 (320) 3,000

2 G2) 73,900

2 (322) 124,450

2B (323) 52,100

2h (324) 18,400

25 (325) 27000

- Transaiseion Plant 1520

2 Total Direct Cost 5,370

ot Construction Services 90,000

Engineering, Desiga, and Constr.

Managenent 60,000

ocean & Tnland Freight 10000,

SUBTOTAL 335,370

Contingency 877630,

?TOTAL $323,000

Unie Cost: $896/t

0.3,

---Page Break---

Ace No.

20

a

2

23

2%

25

26

@

Fee acca

(320)

G2)

(322)

(323)

324)

CAPITAL INVESTMENT

NORCO W0.1

PREPA ESTIMATE

1978 dollars

$103

Land and land rights 2,668

Structures and Improvements 76,689

Reactor Plant Equipment],

Turbine Plant Equipments 136,431

Accesory Electrical Equip. 21/157

Misc. Power Plant Equip.

(nelude in 322-23) _

Main Cond. & Heat Rej.

System (ieclude in 323)

Total, Direct Costs

Consttuction Expenses

Engineering, Design and

Construction Management

Code up grading 4,000

Sub Total Direct and Indirect Cost SI6U93

PREPA Cost to Date (12/77) 19,777

PREPA Cost Future 24,520

PREPA Operator Training.

?and Consultants 5,476

L080

364

Offsite telephone and pover Bt

Sub Total Basar

Contingency Allowance 62,361

1978 dollars Total Cost Ba78,102

Unit Cose: $817/kw

---Page Break---

ese

11139 We PARA

(mid 1976 dollars)

dec #

20 Land and Land rights

a Structure and Inprovenents

2 Reactor Plant Equipment

23 Turbine Plant Equipment

2 Electric Plant Equipnent

25 Mise. Plant Equipment

26 Main Cond. Heat Rej. System

2 Total Direct Co

a construction Services

2 Hore Office Engrs. Service

3 Field Office Engrg. Service

9 ?Total Indirect Cost

Toral Base Cost

Other costa:

(Q) Main Power Transformer

(2) Omers Cost including Consul-

tants, Site Selection, etc.

(2) Additional spent Fue!

(@) Spare Parts

(5) Fees, Permits

?otal,

Grand Sub-total

10% Contingency

Total (aid 1976 dollars)

wely 1978 at 8t/year

Total (1978 dollars)

init cost: 968509/i

s103

2,000

101,375

133,48

11,281

395428

12,803

21588

330,957

70,033

49,220,

128,621,

2473874

308,851

2,000

48,850

8,000,

3,200,

12400

3,480

632,281

63,228

$8695. 509

85,109

$780,618

?capital Cost: Pressurized Water Reactor Plant, NUREG 0241

0-5

---Page Break---

vEic

11190 BR

hee. 3103

20 Land and Land rights 2,000

2 Structures and Iaprovesents: 13,324

2 Reactor Plant Equipnent 125,734

23 Turbine Plant Equipment 116,673,

2% Electric Plant Equipment 40,746

25 Mise. Plant Equioment 12,075

% Main Cond. Heat Rej. System 21,989

2 Total Direct costs

a1 construction Services

92 Hone Office Engr. Services

23 Field Office Engr. Services

?Tote? Direct Costs

?Total Base Cost

cose:

Q) Vain Power Transformer 2,000

(2) omors Cost including Consultants, 487850

Site selection, ete.

(3) Addicional spent Fuel Storage 8,000

(@) Spare Parte 33200

(6) Fees Permits 3,500

Subtotal 53,350

Grand Subtotal 646,298,

10% Contingency 94630,

Total (mid 1976 dollars) 710,928

Escalation to early 1978 at 3t/year 86,995

?Total (1978 gol lars) $797,923 ?

Unit Cost: $670/KH

* capital Cost: Soiling Water Reactor Plant, NUREG-0242

D6

---Page Break---

APPENDIX

CAPITAL COST ESTIMATES

RESIDUAL, OIL FIRED POWER PLANTS

---Page Break---

PREPA CONSUL-TANTSA

STIMATE

POR

450 0 OTL PLANT (436 me net

FPC Ace $103

311 Structures and Inprovenents 14,300

3:2 oiler Plant Equipment 63;400

314 Turbine Generator Plant Equip. 6,700

(excluding turbogenerator)

313 Accenory Electrical Equipnent 3,770

316 Mise. Pover Plane Equipeent 710

353 Main Power Transforser 29

Total Dixect cost 21,600

Indirect Construction Expense 30,000

Ocean Freight, Litheragey Trucking 5,000

Engineering, Design and Construction Met. 11000

Subtotal Direct and Indirect 337,600

Contingency Allowance 27400

subeotat 165,000

Escalation AlLovance 69,820,

Interest during construction 42/569

27382

Alder for Turbo-Cenerator Aijustuent 25,000

Total cose, 1985 307.382

1985, Capital Cost $693.54/kw

Plant Net Heat Rate (75% Load Factor) 9200 Btu EWR

ee

* Personal Communication Mr. José A. Marina, PREPA (1979)

£2

---Page Break---

PRIX

1000_ys OTL. POWER PLANT

Unit Capital Cost (1978) 4 40.0 s/xw

Most Likely range (1978) 405-480 8/KN

Ave. Annual Heat Rate 9500 Beu/kwh.

Gost based on burning residual of1 with sulfur content of 0.4%

or less to meet the 1976 NSPS Standards.

Cost escalation at 8% per year

2985 cost 756 $f

1985 most

ely renge 694-822 $/xW

+ EPRI, PS-866-SR, Special Report, June 1978

£3

---Page Break---

APPENDIX F

LEVELIZING FACTOR FORMULA

Pa

---Page Break---

MEVELIZING FACTOR FORMULA

FEVELIZING FACTOR FOROTA

Tn power plant econonics, it is necessary to have the investment,

fuel and operation and saintenance costs on the sane basis so that

they can be added.

Te capital investnent charges are multiplied by the fixed charge

In order to do the sane

with fuel and operation and maintenance, they have to Se levelized

over the Life of the plant since they ate subject to escalation from

year to year.

The derivation of the levelizing factor is presented

a8 follow

let Fey = levelized unit fuel cost during plant lifetime of n

years

n= plant Life in years

Pui = present vorth factor of the yearly uniform series

values of Fy at an interest equal to the discount rate

4 or cost of money

i= discount rate or cost of money

Fo = first year or initial unit fuel cost

4 = actual ave. year to year inflation rate of the product,

saterial or service. It is the result of the multi-

Plication of (1 + infl)(1 + escalation) where escala-

Hon follovs strictly the trend of product availability

and the supply-denand market,

2

---Page Break---

r effective discount rate corrected for total in-

flation such that L+ r= (+/+ ue

Pe present worth factor of yearly uniform

values of Fo at interest rate r. (

rected for inflation),

With the above definitions, thea

F(A) = Fo (Pir)

or Fe = Pir Fo ay

Pa

Fa can be expreased a

a = Case 1? (o00r.). (Ry. 20-6 @

Where, F, = fuel cost in mille per kwh

Pe coal price in dollars per MBTU for base

year including all costs such as carrying

charges on coal storage.

er = fuel escalation factor

x = number of years between year of fuel cost

basis and beginning of comercial operation

BR = plant heat rate in BTU/KHR,

fed fuel cost in mills per kwhr can be expressed

Present worth formulas, as follows:

Fs Gtep ¥ 90m . Gena ._< aaye

PO RE a? debe

The levelizing factor L is,

L = Gra . ase

rade ?Gy

Ba

---Page Break---

APPENDIX G

OTEC PLANTS CAPITAL INVESTIENT ESTIMATES

---Page Break---

JOINT EFFORT BETWEEN FLECTROTECHNICAL LABORATORY, MITI, AND

RESEARCH AND DEVELOPMENT CENTER, TOSHIBA CORP.

OR MAJOR SPECIFICATIONS AND COSTS CF 100 MW OTEC POWER PLANT?

I 1975 1976 | Sour A278 Toyama

' ees seeiee pesisn __| project Project

| crous paver ostrut(is) | 100,000 100,000 {100,000 100,000

m,210 | 26,270 sa,c0 |

Anonin Vpeonia Anovia,

{a rret0? voto? | 0.908220

: 28 26.

| mesic vere watertee/s) | o.sesne® | s.zaao® | p.eireo8 6.90n08

feelin ite 1 tase om

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[naa tee seesefes area 3.2105 3.106x205_ | esas 2.142105

units ! 16. + 8 i s 8

pee Serssfer ea | syao! a.somio> | 2.s4s08 a. amass

sb upits i 16 2 8 8

r/c output) t unite | 25,000:4 25,000; | 28,000;4 25,0004

type of pletfore Nectanssiar | suteergee | subeersee | surface

renee sarge Guinter | ?qninier ats

unit construction

Tose ls) 206 {see en nr

Tax Orarview of the ?GTEC Tevelopecnt, T. Homa & K. Kanogava, 6th. OTEC

Conference, Shorchas-Anericena Hotel, Washington, D. Cr, dune 19-22, 1979,

ce

---Page Break---

3 Technology, lnc. (F

Searibilay Design Sti

jechnology toc. (Fluor Corp.)

Cost Summary, Mi2iione of Dolles

Yavagement-Deeign Phase

Nosagenent acquinis:

A Devolyment stare

Yansgenent Syetem Operations

Scsocrt Phase

Cesena) Managesent

Concestual Design

Land Saced Containsent Syst.

cone Kater Pipe Systen

Mare Vater Pipe Syetes

Eeergy Travsfer System

Energy Utilization Syst.

Acceptance Testing

Deployment Services

Industrial Facilities

Engineering & Det

Const. Deployment Total

Operation & Support Total

OTEC Synten Total (xt

*Vapobliched information.

?ind Based OTEC Plante

Fuerte Rico)

2980)

18.7

sire

February 1979

---Page Break---

Additional Reported Cost Fatinates of OTE

ts. Different Sources.

AL HUROCEAN. Association Europeene

Ccanicue. Bengt A.P.L. Lachmann

20 Ye Plant. Estimated Cost $5000/KW* (1979)

Metrek Divieion ~ The MITRE Corporation

¥ cobsen & RY. Manley

N00 ite Plant (Offasore Flor?da Peninsula)

Eetimated Cost $2579/K¥ (1976 dollare)*

©, Blectrotechnical Laboratory - MITI, Research &

Development Center, Toshiba Corp.

2 Cost. $16700/KK*

?Co, 2979, Setimated

pet cuspur. (2875)

Costs 8220-8

?FGak, CIEE Conference, ShorehamAnericana Hotel, Washinton, D.C.,

Jone 19-22, 1979.

---Page Break---

Appendix A

B

vo

LIST OF APPENDIXES

coal

Interest During Construction and Inflation

Forma

Goal Plent Capital Investment Estimates

Neclear Plant Capital Investment Estimates

Capital Cost Estimates Rosidual Oil Fired

Power Plants

Levelizing Factor Formla

orc

ants Capital Investment Estimates

Feasibility Study for the Use of Large

ndpower Generators in Puerto Rico

---Page Break---

APPENDIX #

SIBILTTY STUDY FOR THE U!

OF LARGE WINDKPOWER

GENERATORS IN PUERTO RICO

Prepared by:

Dr. RaGl Erlando Lépez

HL

---Page Break---

introduction

in the face of continuing rising fue! costs, attention has been focused once more on the windpower systems

Of yesteryear. Large 1.5 megawatt turbines are being

Geveloned for use in electric power grids. By intecrat~

ing these systems within a fossil-fuel power-plant net~

work, an inexpensive method is achieved for storing and

uleting the intermittent and variable output (due to

the variation of the wind) that the wind turbines produce.

energy from the wind turbines, generation at

1d be reduced an amount egal to the

the fuei that would have

To store th

been used by the # owerplants can be stored

1 have heen served by

be served by che energy pro-

vided by the wind turbines, This scheme is simi

lar to

planned for Sweden (1-4) and for the Colerado

Siver Storage Prosect in the Western United States (5).

PREPA could install wind turbines at sites with high

ipower potential and link them to the network. In

18 way, the enerey storage capability of the thermoelec-

tric facilities cen be used even if the wind turbines are

not colocated with them.

shat being

Large wind turbines are being designed, built and "6 by the General Electric Company under contract with D0 and Nasa. These 1.5 megawatt, 61.9m-diameter units will be available commercially in the very near future, The initial cost of the wind turbines is antict- pated to be very high until full mass production is achieved. However, as more units are acquired by dif- ferent utilities and production costs decrease while

te

foseit fuel prices increase, a competitive breakeven

point will be reached.

---Page Break---

A study has been made of the feasibility of inte-

grating large windpower generators to the existing PREPA

exmoslectric network in Puerto Rico. the findings of

that study are presented in this appendix. 2reliminary

assessments of wincpower, windturbine performance and

costs have been made.

---Page Break---

?The island of Puerto Rico lies in the zone of

the Trade Winds. ais is one of the most persistent

egimes of the world (6). However, as these

northeasterly winds flow over Puerto Rico, they are

modified sy the topography of the island ana by the reainnd breeze. This breeze is established by the

temperature gradient between land and ocean. These

two ef:

fects can act to increase or decrease the speed

of the Trades in ce

er Giurral and recional patterns.

ing the day, the lené heats up while the

colly at the same tenverature. The

reeultine tenperature cradient between lane an

ts ford)

ocean

fer emphasized by the fact that e good portion

of the heating occure at heights of up to 2.000 Feet

As the temp

ration of the wind occurs.

= (mostly east-west) mountain ranges.

ture gradient develops, an inland accele~

On the north coast of the island, this accelera~

tion is directed from north to south adding to the

strength of the prevailing northeasterly Trades.

Figure 1 schematically portrays this effect. The

thermal acceleration in the south coast is directed

from south to nerth, reducing the strength of the

?Trades and converting them to south easterlies.

The east coast of the island suffers an easterly

thermal acceleration which can increase the strength

of the Trades considerably. The west coast, however,

experiences a westerly thermal acceleration which

opposes the north easterly Trades and sometimes

Boo

---Page Break---

---Page Break---

reverses then into weaterlies. The resulting winds

can be very slow.

During the nicht, the land cools off ang the

thermal acceleration is directed toward the ocean.

?This acceleration is much weaker than

\e daytime

one. The effect of this noctura! acceleration is shown in Figure 2. As the Trades flow inlend at the

north and east coast, they are opposed by this accele-

zation. Although the wind over the land is not as

strong as it is over the ocean, a good breeze is

cavsed by cer

ally weak thernal cradient. During

ty of the low layers of

This ©)

the night the +!

the atmospher=

he verti=

cat exchange of tween the suriace of the

island and the

ving over the south and weet

coast from the the w:

vsvally ales

own and is sustained only by the weak seaward accele-

ration that is established curing the night and early

Thus, ctinatologically one could expect the high-

est potential for wind power utilization on the north

and east coasts because the wind ig higher in these

regions during the day ani night. Figures 1 and 2

fare schematics of the efiects of the ses-land breeze on the wind

power potential in Puerto Rico. Specific details of

these effects depend on the particular topographic

configuration of the region, the season and the time of the day. These maps, however, provide a guide for

the analysis of the limited wind data available and

the extrapolation of the analyses to data-void

regions.

---Page Break---

---Page Break---

- Diurnal osetllation of the wind speed and che cor-

Figure 3 portrays the variation of the speed of

the wind with the time of the day at representative

stations in the north, south and westcoasts of Puerto

Rico. The locations of these ané other stations are

indicated in Figure 4. These values correspond to

the standard anenoneter height of 10 meters. as

expected, San Juan on the north coast experiences the strongest winds. A maximum of 17 mph is observed at 3.P. M. when the trades are reinforced the greatest by the thermal acceleration produced by the daytine temperature gradient between land and water. ?the Weakest winds (9 mph) occur just before sunrise when the reversed land-water temperature gradient becones lergest. the winds at Guayanilia on she south coast are highest (22 mph) at 1 P.M. but are mich lowes than at San Juan. Mightime wind speeds are very low {around 4 mph). Mayaguez on the west coast. shows the weakest wings of all three stations with a maximn of only 10 mph at 2 P.M. and a minimum of 2 mph before sunrise, A diurnal sumary for a station in the east coast is not readily available.

?The differences in the patterns of these asurnal variations in wind speed are reflected in the values of the average wind power density for each of the stations, Table 1 presents the average wind power density in a vertical plane perpendicular to the wind direction (watts/n®) during a typical day for the stations mentioned above.

These values were obtained from

ov?

rea)

8

---Page Break---

Figure 3. Diurna? oscillation of the

wind speed at selected stations.

No actual observations were

recorded at Mayagiiez during the

night and early morning hours.

All values correspond to a height

of 10 meters.

---Page Break---

ISLA VERDE

< Pes :

é ?<

gure 4, Map of Puerto Rico indicating the

locations of meteorological stations

for which wind data is available.

---Page Break---

Table H.1

Average wind power density in a vertical plane

perpendicular to the wind direction (watts/n*) during a

typical day at selected stations in Puerto Rico. values

correspond to an anenoneter height of 10 meters.

North Coasts .

Isla Verde ' 122.5

Bast Coast .

Roosevelt Roads ' 93.0

South Comes .

Guayanitia . 25.2

West Coast

Mayaguez ' 13.5

HLL

---Page Break---

Frequency

*

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Bers eueyamana

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2 wovsren nouns

3 t ??_

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wine sPceocurn

Figure 5. Frequency distribution of

hourly wind speeds for

representative stations of

the west, south, north and

east coasts of Puerto Rico.

---Page Break---

where p is the power density, p the air density at

anemometer height, and v is the wind speed. This for-

mula was applied to the wind speeds shown in Figure

3, and an average value obtained for the day. The

Power density for Roosevelt Roads on the east coast

was obtained from a 5 point yearly windspeed frequency

distribution.

?The north and east coasts have the largest power

Gensities (222.5 and 93.0 w/m") with the south and

the west coasts having much lower values (25.1 and

13.5 w/m'). ?The wind power at Mayaguez is extremely

jow. The differences in wind power density between

stati sh larger than the &ifferences in the

patterns of diurnal wind speed variation. The reason for this effect is that the cube in Equation 1 amplifies

Seemingly small ¢ifferences in wind speed when power

density is computed.

?The different diurnal wind speed patterns produce

very different frecuency distributions of winé speed

during the year, Figure 5 shows frequency distribu-

tions for the four stations considered so far. It can

be noticed that as one moves from the west coast to

the south, and from the north to the east coasts the

maxims frequency occurs at higher wind speeds. The maximm fre~

quency for Mayaguez corresponds to 0-4 mph, for Cuayanilla 4-8 aph,

for Isla Verde 4-8 mph also but at a mich larger frequency, and

8-12 mph for Roosevelt Roads.

13,

---Page Break---

Distribution

In order to construct a map of wind power potential for the island, wind éata was analyzed for the sta~ tions indicated in Figure 4, A detaited frequency distribution of hourly wind speeds was readily available only for Guayanilia I, Distribution with only five or six

wind speed classes were used for all other stations.

In the latter case, detaited frequency distributions were

reconstructed using the following method!

a. obtain a cumulative frequency distribution

>. £it 2 2nd order polynomial to this cumulative distribution.

cs coemute detain

Fouetion © was then applied to each of the wind speed

stributions fron the adjusted

eval 1 mph) and the average wine power den-

sd

sity was comp)

?The results are presented in Table 2. The results

again indicate that the east coast ie the region with

the highest wind power potentiat, followed by the north

coast. The south and west show only one third the powe:

available in the east. It is interesting to note that

separated by about 75

miles have very similar power potential. Contrary-wise, the stations ¢ south although all fairly low, differ considerably among themselves. Guayanilla 1 is farther

the two stations in the nort!

inland than Guayanilla IT which is more exposed to the sea breeze effects. These local differences stress the need for a detailed wind survey before choosing the

final site for 2 generator plant. ?The effects of valleys, ridges, exposure, location within the seabreeze circulation, etc., should be carefully considered.

HL

---Page Break---

TABLE H-2

Averace wind power density in a vertical plane perpendicular

to the wind direction (watts/n2) during the year at selected

stations in Puerto Rico. Values correspond to an anenoneter

height of 10 meters.

North Coast

Ramey

isla Verde

Bast Coast

Roosevelt Roads 173

South Coast

Isabel yo

san?

Guayanilla I (Fomento) 16

Guayanilla 11 (PPG) 33

West Coast

Mayaguez 26

He1S

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?The stations available are all within the populated coastal plains. It is important to assess the potential in the mountainous interior as well. To obtain an estimate for the elevated regions the following method was employed:

2. Obtain the frequency distribution of free-air wind speed at heights corresponding to the elevation of the terrain.

2. Apply Equation 1 after obtaning the air density appropriate to the elevation of the terrain.

+ Correct the resulting power for su

effects.

ce friction

The United States Weather Service takes periodic upper siz observations at its Isla Verde Airport station. Unfor- tunstely, the data is not readily available in a summarized way by wind speed for different elevations. Col6n (7)

however, has presented some summarized data for a height Of 5.000%. From this information, a preliminary frequency distribution was reconstructed for free-air wind speed at 5,000 feet.

?This height falls within the surface frictional layer wnich can extend up to 6,000 £t in the region. Thus, the winds at 5,000 feet should be related to the surface winds. A power law of the form:

ar

U(z) = Ula) (Z/ay @

(where u is the wind speed, z is the height of interest,

and a is a reference height) has been used to relate winds at different heichts near the surface. when this equation was applied to the average Isla Verde wind speed at 5,000 feet (17.1 mph) and 33 feet (8.4 mph) an excellent fit was

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achieved. In view of this good fit and for lack of a better relation ship, it was assuned in this study that the free-air wind speeds over Isla Verde are related by Equation 2 for the layer of up to 5,000 feet. ?Thus, the frequency distribution obtained for 5,000 feet was aseuned to be valid for the entire layer after correction is made for the de~ crease in wind speed according to Equation 2.

?The wind power was computed fran Equation 1 for heights of 500, 1000, 2,000 and 2,000 feet. The correspenting air density was obtained from the mean West Indies sounding of Jordan ©), A factor of 1/3 was applied to the computed pover to allow for frictional drag effects as air hits the elevated terrain, The adjusted powers constitute an of the average wind sover available at 23 feet over the ground

ferent eelevations.

Figure 6 is a map of Suerto Rico shoving Lines of equal wind fensity (watts/t?). The Lines follow the 0.5, 1, 2 and 3 thousand feet neight contours. The value represented by the Lines correspond to the vower censity conputed for those heights as described above.

?The point velues cbtained for the coastal stations are indicated sepa~ ratedly on the mp, ?The effects of river vatleys and canyons and local terrain accidents have not been included in this general map. Local va- ues of 85 watts/n* are probably possible on the tallest (3,500~6,000 feet) peaks, Tt can be seen from this map that the highest wind power poten=

tial is found in the east coast and along the island mountain divide,

?The determination of the optimm location for @ wind energy conversion

system would have to nade after a detailed wind survey at the two more

promising areas (cast coast and divide), ne of the most important

factors to consider is the variation of the

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wind speed with height up to the hub height of the pro-

posed turbine. The basic problem is to determine if the

accelerating effect of the sea breeze on the coastal plane

of the east coast provides a higher wind power at hub

height than the stronger speed of the fri air wind as it passes over the top of the tallest mountains at hub heihgts. From this preliminary assessment it seems that an east coastal site would be as advantageous from the point of view of available power, accessibility, construc~ tion and operation, In the economic study which follows, the Roosevelt Roads station, will be used in the computations assuming that the wind energy generators would be aced there,

mine

ne perf

Two mogels of wind turbines are being designed and tested by the General Electric Company: a 500 ki unit, assured to operate at a 12 mph median wind site, and a 1500 kW unit, assumed to perate at an 18 mph median wind site (7). The proposed design characteristics of these two units were used to estinate the enersy that could be generated at a site 1ike Roosevelt Roads.

?The wind speeds of the frequency distribution for

Roosevelt Roads were adjusted to the height of the hub

the two turbines by using the power law of Equation

2, Then, the characteristic power-va-wind-epeed curve

of each turbine was applied to the adjusted wind-speed

Gistribution. ?the 1,500 ki unit would produce an

average yearly power of 288 kW of 2.52 x 10° kwh during

the year. The 500 kW turbine would generate an average

of 236 Ki or 2

figured were used in an analyaia of the cost of the power

generated by arrays of these turbine, and they are

presented in the next section.

© kwh during the year. ?These two

ue19

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?These figures were obtained by employing the

following concepts:

For a wind frequency distribution £(v), where v is

the wine speed, the average power F generated by a

wind turbine can be obtained as (Justus et al., 1976)

Fe flew) P (wav, @

Here Plv) is the power produced by the turbine as a

function of the wind speed. The function Plv) is a

of the particular wind turbine used.

tion can be characterized in terms of

speed vo (the lowest wind speed nece~

ssary to start moving the blades of the turbine)

b. Design speed vy (the lowest wind speed at

which the turbine produces the maximum power Pm

for which it was designed

cc. Cut-off speed v2 (the maximum wind speed at

which the turbine can operate)

4. Maximum power Pa.

For speeds below vo, the generated power is zero,

Between vo and vz, the generated power usually varies

in a parabolic fashion. when wind speeds above vz

are experienced, the angle of attackc£ the blades is

changed so that the generation of pover is constant at Pn.

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Above v, the blades are furled m that they do not

rotate in order to protect the turbine: the generated

power is naturally zero.

analytically, this pattern can be expressed ae

VevQ

VosvE¥y

eve oe

vy <vevy

vv,

In this relationship.the-wind speed is assumed tobe

given for the height of the hub of the turbine. A,

B, ané C are the coefficients of the parable that

expresses the variation of the generated power between vp and vie

icients can be obtained from the following

atavytevg2

By #04? w

BABY, HCvy 26,

ABV ICve2=P(vg/¥y) ®

where vo=(votv1)/2. This last relationship expresses the concept that the power generated is proportional to the cube of the wind speed.

?The assuned power-vs-wind speed cirves can be characterized by the following constants.

Heal

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AL 1500 kw unt B. 500 ky unit

vorll-4 mph vor7-9. mph

vye22.5 aah vyei6.3 mph

?¥2750.0 mph v2"40.0 mph

F5r1500 Ir 500 kw

These values were substituted ?in Equation ané the

coefficients A, B, C were evaluated. This completes

the evaluation of the function P(v) of Eqn. 3.

?The wind speeds classes of the frequency distri-

bution for Roosevelt Roads were then-adjusted to hub

height by using the power law of equation 2 (154 and

150 £ for the 1500 and 500 kW units}. With all this

proper unit conversfohs, Eqn. 2 was

information, a

evaluated over the different adjusted wind speed classes

of the fre:

y distribution to yield the average

yearly powe ?The procedure was projramned for a

72-59 ?esk calculator.

Heze

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XV Economic analysis

System configuration

The hyéroelectric system of the PRNRA produces approxinately 100 x 196 kin every year. To achieve a similar generation it would take approximately 50 wind turbines. preliminary studies by GB have indicated that the wind turbine units should be installed with a separation equivalent to 15 diameters, or appro~ ximately 920 m between units. For a cluster of 50 units that would cone to a nininum of 9 square miles of land needed for turbine installation alone. The entire Roosevelt Roads Naval Base Zo: convarison, covers an area of 12.5 square miles. A more manageable cluste: of 25 turbines would be more commensurate to

fons of the island, xt is also possible to have

and north coasts. For

study, a cluster of 25 turbines was considered.

fective layout could be as portrayed in Fig. 7.

tne purzoses of

2. Land costs

?The land needed for the assumed layout is 2,891 acres (2,978 cuerdas). Current lané prices in Puerto Rico fluctuate between $5,000 and $25,000 per cuerda (1 cuerda equals .9712 acres). Due to the large amount involved it is reasonable to assume a low wholesale price of $5,000 per cuerda. An 8% yearly increase is assumed in land prices. The present land costs would thus amount to $14.89 millions.

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3. Wind turbine generators costs

Preliminary cost estimates? provided by GE have indicated that the first production 1.5 kw would cost approximately $2.633 million. The 500 kW unit is estimated to cost 72.5% of this price, or $1.91 million. For initial planning purposes, GE also estimates that the accumulative average production costs can be reduced to 99% of the previous costs, each time the total number of units ic doubled.

?The manufacture of one turbine has been estimated by GE to take 6 to 9 mon

So purehes

?The Bureau of Reclamation (5) is considering

49 turbines in the first 5 years of production.

Other convanies might enter into the wind turbine manufacturing

business, A production of 100 un

every 5 years will be

essumed in the present study. Assuming a 90 percent learning

curve, the average cost of a 1,500 kW system within the first

100 units {first 5 years of production) would be $1.31 million,

ané $0.95 million for a SOC EW unit. The total cost of the

25 turbines would be $32.75 and $23.75 million for the 1.5 and .5

kw models respectively. These costs ii

delivery, erection, land preparation ana check out costs.

ude equipment, assembly,

Rvery year the purchase is delayed the price will come down fon the account of increased experience in the part of the manu- facturer, but on the other hand, the price will go up on account of infla

Electrical connection costs and overhead

?The Bureau of Reclemation has prepared a preliminary design as the basis for an estimate of the electrical interconnection costs £

their wing turbine array of 49 units as well as the transmission facilities required to tie into their existing transmission grid. ?Their azray would be twice as big as the one sssumed for this study. Their costs have been estimated to

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Jo qeqsnzo w 103 anoker poysabins +, ?Br

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be $6.37 million for their Wyoming site. Half of that amount

could be assumed for the array of 25 units in Puerto Rico, or

$3.19 mi:

?on.

A design overhead of 178 has been added to cover engineering

design and preliminary and environmental studies. An allowance

for additional site facilities, contingencies and construction

supervision of 15% has also been included.

The total capital investment for the system at this time

is summarized in Table 3. The total cost for the wind turbine

system comes to $62.33 and $50.45 million,if developed at the

a £ Sand .5 MW models respectively.

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Table 3. Capital Investment Summary

Item Capital Cost (million dollars)

1.8 Mw 0.5 Mw

1. Wind turbine generators 32.75 23.75

(25 units)

2. Electrical interconnection 3.19 3.19

3. Design and study overhead (178) ban 4.58

4. Contingencies, site facilities, 5.39 4.08

supervision (158)

5. Total wind power system 47.44 35.56

6. Land costs 14.89 24.89

Total capital investment 62.33 50.45

He27

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5. Wind turbine power costs

?The power costs can be calculated using the capital

investment costs, land costs, operation and maintenance

costs, and the annual estimated power output. A construction period of 3 years is assumed, as well as a plant life of 35

years and an interest rate of 88.

Tt was assumed that construction expenditures would occur uniformly throughout the 3-year construction period and the interest during construction was computed at

compound interest for half of the construction years

(1.022+5), The interest on the land cost was computed at

Amorti-

zation of the total wind turbine investment (construction

compound interest for the 3 years of constructio:

plus construction interest) was computed using a total capital fixed charge rate of 11.7438 as is customary for the PRWRA while amortization of the land investment costs (land plus land fnterest) was assumed at 8% compound interest over the assumed 35-year life of the plant. cE has assumed that the maintenance and operation costs will be approximately 2 percent of the wind turbine costs.

?These costs were assumed to include the generators, elec-

trical interconnections, and contingencies and site faci~

Lities.

Table 4 summarizes the estimated power costs. The total cost comes to $8.68 and $6.92 million for output of 63.00 and 51.75 million of kWh respectively, the power costs for

the two wind turbine systems come out to be 137.8 and mille /kwh

H.28

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Table 4. Power costs

Iten Costs (million dollars)

1.5 MH 0.5 MW

1. Total construction costs 47,44 35.56

2. Construction interest on 5.82 4.35

construction costs

2. Land costs 14.09 14.89

4. Construction interest on 3.87 3.87

land costs

5, Annual fixed charge on 6.25 4.69

construction costs (142)

6. Capital recovery on land costs (3+4) 1.62 1.6.

7, Operation and maintenance -82 +62

cost per year

8. Total annual cost (5,6,7) 6.92

9. Annual power output (106 kwh) 63.00 51.75

10 Power cost (mills/kwh) 237.8 137.7

H.29

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?The Bureau of Reclamation estimated a power cost

of 21.1 mille/kWh for a similar system in Wyoming.

?The great difference in the two figures results from

3 very important factors:

a. the wind power available in the Wyoming site

is 3 times as much as in the Roosevelt Roads

site.

the capital fixed charge rate for Wyoming was

assumed at 8.41 percent, while the PRWRA

reported a rate of 11.743 percent.

c. land costs in Wyoming were figured at $200

per acre while a wholesale price of $5,000

per acre was assumed for Puerto Rico.

It is interesting to note that both turbine

models would produce energy at the same cost but the

larger turbine would produce 18% more total power.

thus, it would be advantageous to use the larger

machines. In what follows only the 1.5 kW turbine

model will be considered.

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V_ Economic projections

?The estimate of 138 mills/kWh applies to the cost of Power if construction was completed within the next 5 years. For simplicity, no inflation factor was included for this period. Certainly, the uncertainty in the learning rate estimates and the manufacturing output do not warrant a more detailed approach. As construction is delayed beyond this period, however, the price will change considerably: own on account of increased experience in the part of the manufacturer, but up on account of inflation.

A projection of the wind vover costs was made for a Of 40 years, This projection was made in eight

per:

S-year steps assuming the production of 100 additional

turbines in each 5 year period with a corresponding 90% learning rate. A compound 8% inflation rate

was also sssumed starting from the costs of the es

mate of Table 4. zt was further assumed that the learning rate takes into consideration the inflation in the production process.

Table 5 presents? the capital investment costs for each of the eight 5-year periods. The greatest érop in the price of the generators occurs in second step. ?The learning curve is basically an exponential curve which drops very fast at the beginning and stabilizes very fast. Other costs, especially for land, escalate very fast on account of the assuned 8t inflation. Actually, land ané interconnection costs become several times the cost of the turbines them-selves. -If an additonal inflation increase is added to

the cost of the turbines the situation becomes hopeless very fast. The largest item becomes the land costs after

40 years of delay. If the land could be secured free of charge, e.g-, land belonging to the Commonwealth of Puerto Rico, or land already belonging to the PRWRA could be used, @ be reeaced @ramatically.

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Fable 5. Forty year projection of capital investment (million dollars)

0-5 6-20 11-15 16-20 21-25 26-30 31-95 36-40

1, 25 generators 32.75 26.15 26.15 22.90 22.08 21.4 20,85 20-40

2 Blectsica!

Interconnections 2.19 4.69 6.89 10.11 14.86 21.85 32.10 47.16

2. poston

overhoae (279) 6.12 5.24 5.28 5.62 6.29 7.98 9.00 22-49

4. Contingeneses

(5%) 5,39 4.63 4.66 4.95 5.54 6.49 7.96 0223

47.44 40.71 40.90 43.87 48,76 57.09 69.09 69.18

5. Land conte 16.89 21.86 92.15 67.29 69.40 101.97 149.83 220.15

62.39 62.59 79.13 90.60 118.16 159.06 219.72 309.33

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Table 6 shows a summary of the power cost estimates for each of the 5-year periods. Again, the effect of inflation overcomes the advantage from the learning rate. Line 9 of the table shows the savings of oil barrels that the wind system could achieve assuming that the efficient thermoelectric plant uses one barre! to generate 600 kWh. Line 11 indicates the equivalent cost of each barrel saved in dollars.

Figs g and 9 portray graphically the investment cost of each kW produced and the equivalent cost of each barrel of oil that could be saved by the wind energy conversion system. For reference, the portion that the land and the turbine purchase would eecount for is also portrayed in Fig. 8. It should be realized that in the computations figured above, no provision ?thas been made for outages or auxiliary

power for the turbine. In view of the inaccuracies in some

of the assumptions this correction becomes insignificant.

=f a more detailed estimate is desired, however, the total

annua power output could be reduced by a factor of .90X.99

which is a reasonable figure for outage and auxiliary power,

respectively.

Line 12 of Table 6 shows the equivalent cost of each

barrel of oil saved if the land cost could be eliminated.

the equivalent cost could be around 60-70 dollars per barrel

for the next 25 years. In view of the present upward trend

in {1 cost, the equivalent price could become competitive

in the foreseable future. Lan@ cost could be eliminated

by using land already owned by PRWRA or ceded to PRWRA free

of charge. Pig. 9 portrays graphically the equivalent cost

of a barrel, of oil under these assumptions.

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pouLaasywer kw

Fig. 8. Forty-year projection of the equivalent cost of each kW produced by the wind-energy conversion system.

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Fig. 9. Forty-year projection of the equivalent cost ?of each barrel of oi} saved by the wind-energy conversion systen.

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VI summary

A study has been made of the possibility of integrating large windpower generators to the existing PRWRA thermo-electric network in Puerto Rico. Climatologically, one would expect the highest potential for wind power utilization in the north and east coasts because the sea breeze acts to intensify the prevailing winds in those regions. actually, an inspection of the available stations around the island reveals that the largest power densities are found in the north and east coasts. The power at the south and west coasts being very low. Estimates of wind power density for other regions, especially the mountainous interior, indicate that no appreciable advantage is found in the mountains over the eastern coastal plains.

A station in the east coast, Roosevelt Roads, was subsequentiy chosen for detailed analysis. Applying the design characteristics of the GE 1.5 and .5 MW to the wind speed Aistribution for thie station reveals that an average power of 288 kW end 236 KW respectively, could be generated throughout the year.

A systen of 25 turbines is proposed. Estimates of capital investment, operation and maintenance were made

for systems of the two models. The total power costs were estimated at 137.8 and 137.7 mill/kWh. Three major factors account for such an elevated production cost:

(2) the wind power potential is moderate

(2) the capital fixed charge is very high

(2) land costs are extremely high.

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A 40 year economic projection was performed. In general, reductions due to the assumed learning curve were more than compensated by the inflation rate of at. ?The largest item being the escalation of the already high land cost. If lané costs could, somehow, be eliminated, the equivalent cost of each barre! of oil saved could be aroune 60-70 dollars for the next 25 years, A price that could become competitive in the foreseable future. Land costs could be eliminated by using land already owned by PRWRA or ceded to PRWRA free of charge.

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