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APPENDIX

3.8.2-3

# TRAINING COURSE IN ENERGY PLANNING

Conducted by

Center for International Energy Development
Energy and Environmental Systems Division
Argonne National Laboratory

Course Notes

May 13 - June 7, 1985

Project No. 263-0123.1

PASA No. IEG-0123-P-ER-3089-00

# NATIONAL ENERGY ANALYSIS
# TRAINING COURSE
# FOR
# ORGANIZATION FOR ENERGY PLANNING

## INDUSTRY
## ENERGY DEMAND ANALYSIS

PREPARED BY

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ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION

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ARGONNE, ILLINOIS 60439

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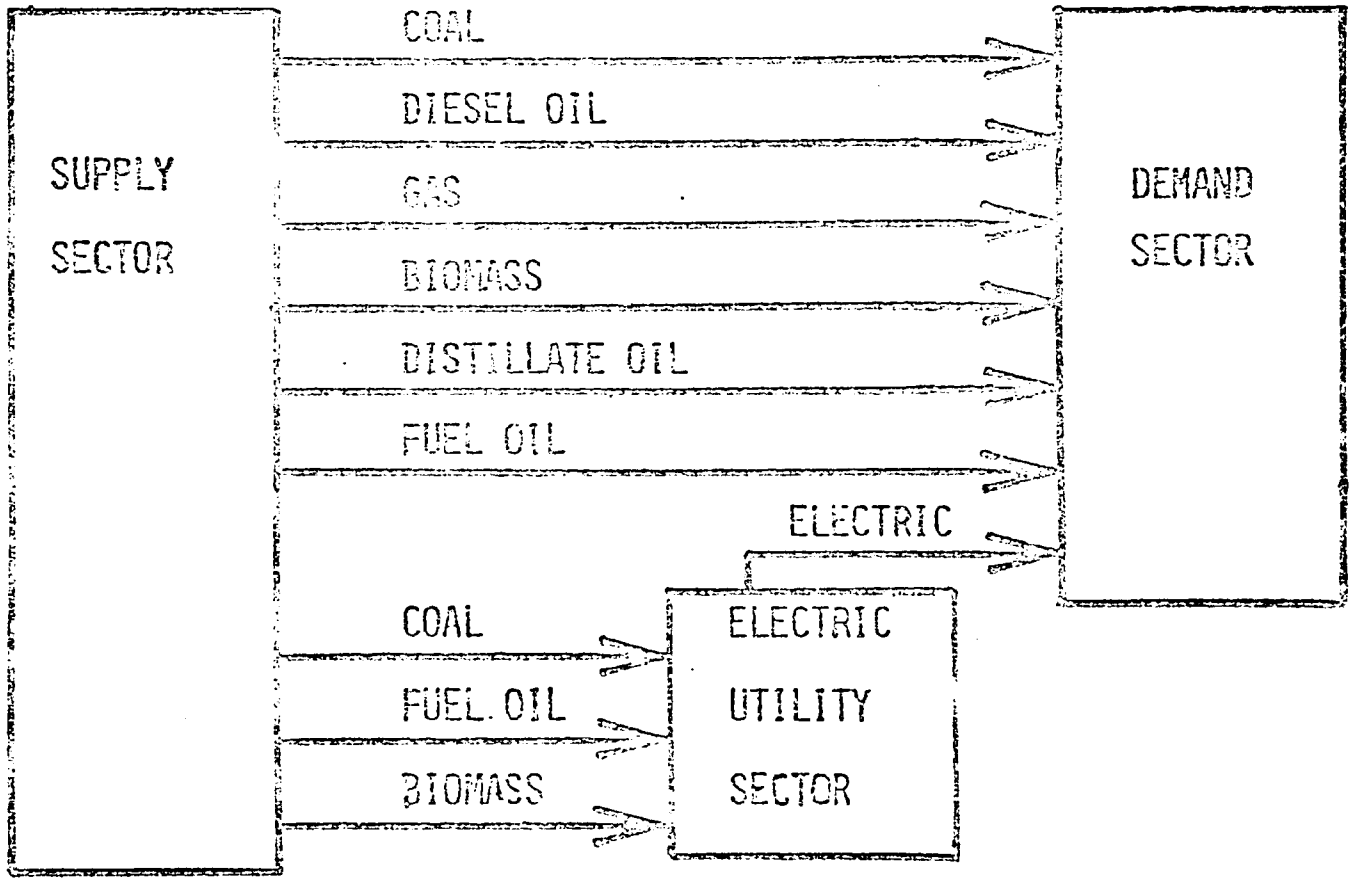
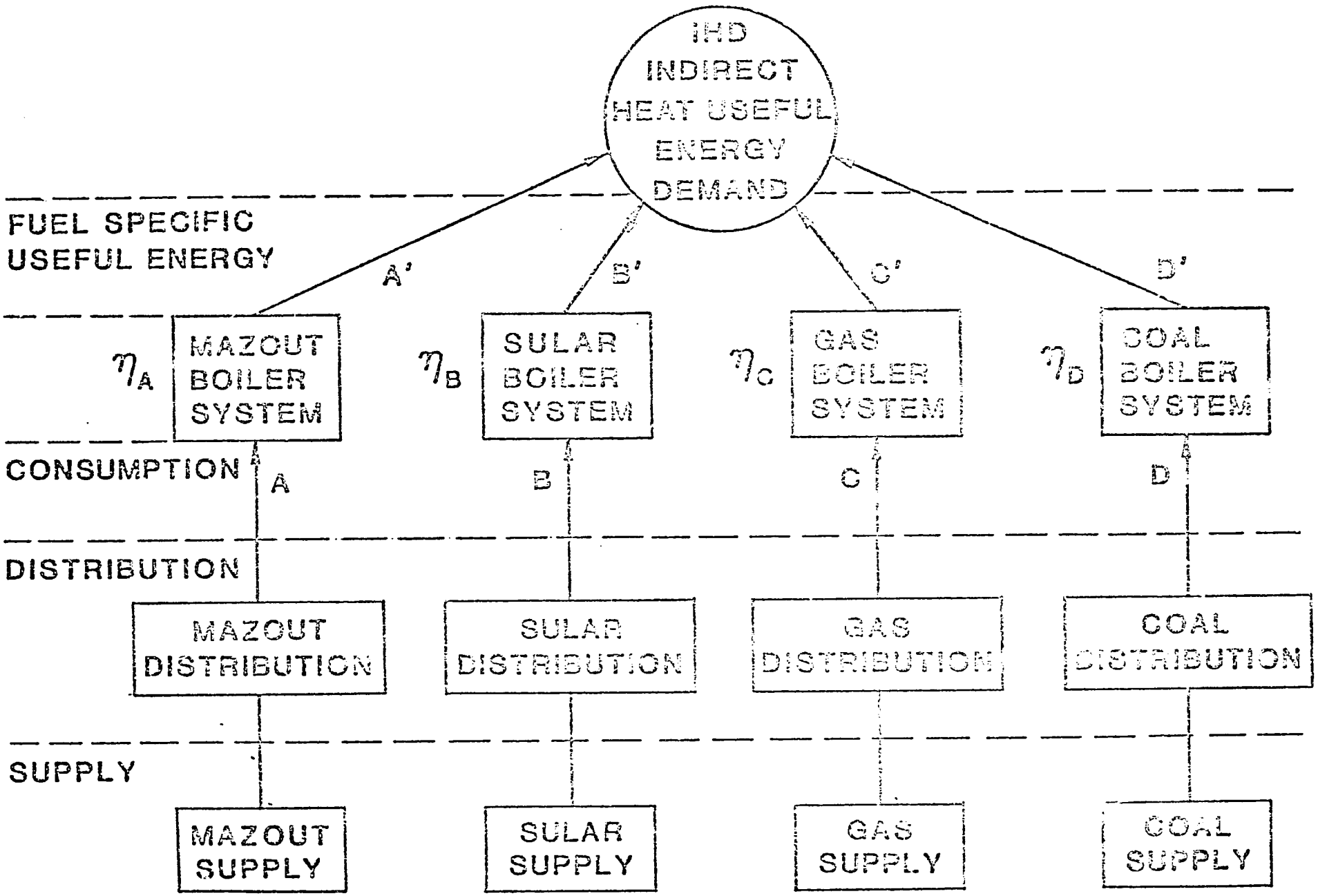
BASE YEAR BALANCE

QUANTITY (BTU/YR)



# DIFFERENT FUELS TO MEET ENERGY DEMAND



DEFINE THE DEMAND SECTOR

- SPECIFY MAJOR SECTORS
- SPECIFY SUBSECTORS WITHIN MAJOR SECTORS
- SPECIFY TYPES OF ENERGY FLOWS FROM SUPPLY SECTOR

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CRITERIA USED FOR SECTORAL DEFINITION:

- o MAGNITUDE OF ENERGY CONSUMPTION
- o ANTICIPATED SIGNIFICANT FUTURE GROWTH CHANGES
- o SPECIAL (EXPENSIVE) FUELS OR FEEDSTOCK
- o RELIABLE DATA AT LEVEL OF DISAGGREGATION

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IDENTIFY HOW ENERGY IS CONSUMED:

- MAJOR SECTOR AND SUBSECTOR
- ENERGY TYPE (E.G. MAZOUT)
- ANNUAL QUANTITY
  (E.G. TEP - TONNE EQUIVALENT PETROLEUM)
- END USE DEVICE

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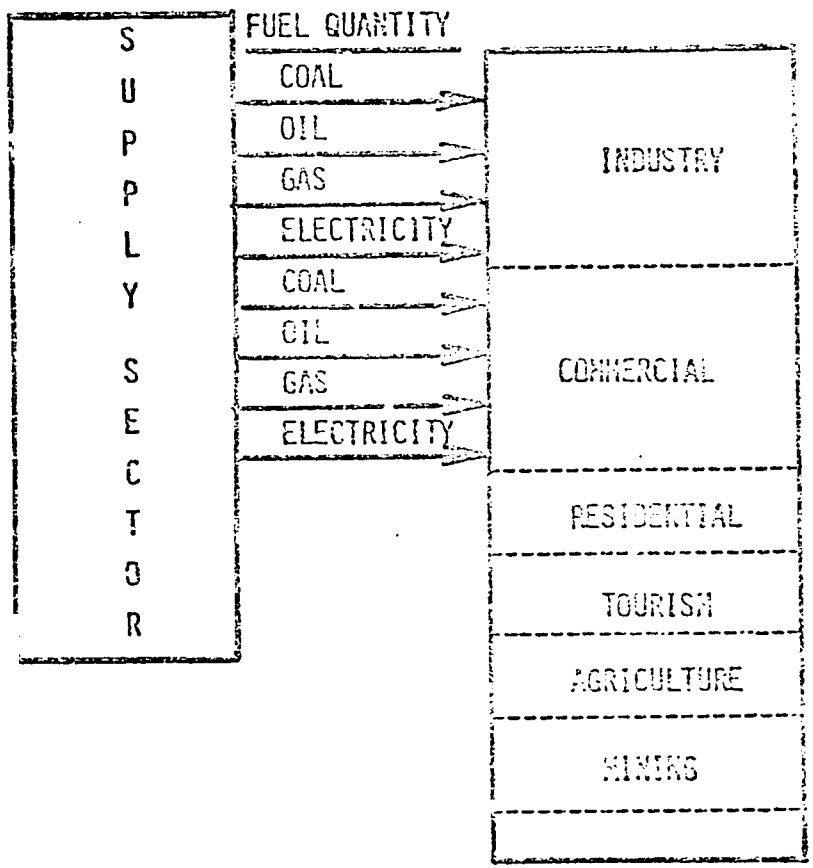
BASE YEAR BALANCE - DEMAND SECTOR

FUEL ALLOCATION




DECIDE ON MAJOR SECTOR BREAKDOWN

- SHOULD AGRICULTURE BE A MAJOR SECTOR?
- SHOULD AGRICULTURE BE COMBINED WITH FOOD PREPARATION

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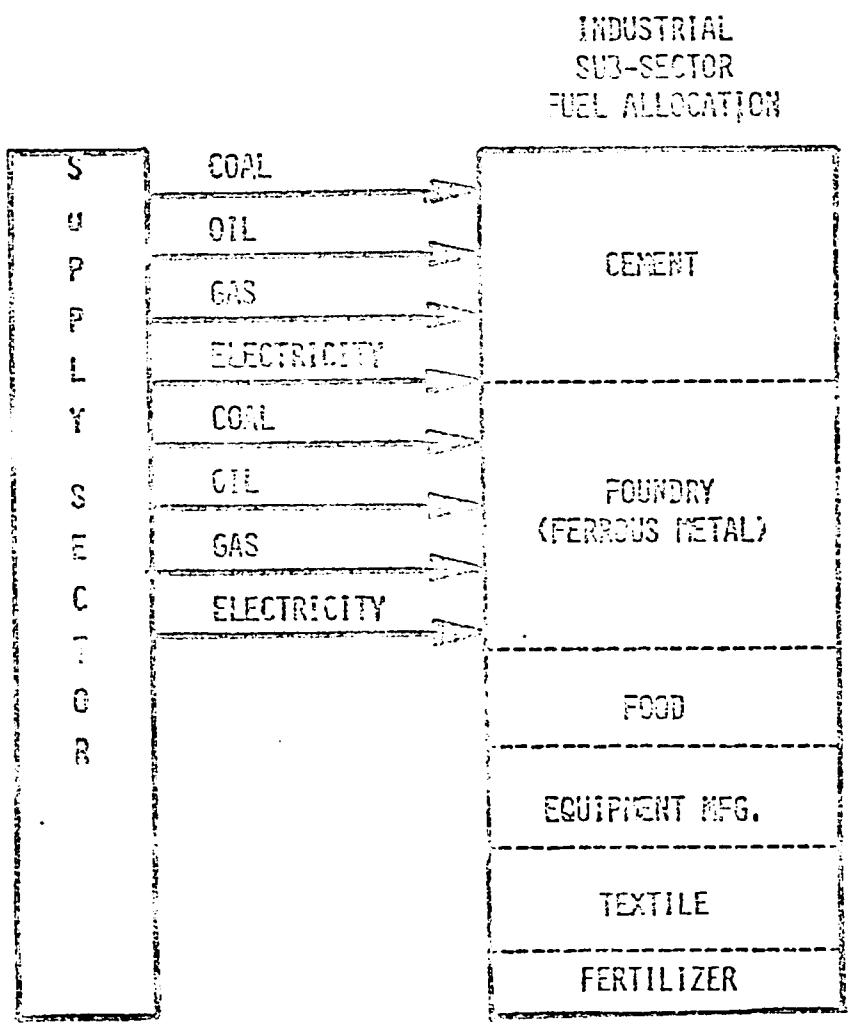
# BASE YEAR BALANCE




- DECIDE ON INDUSTRY SUB-SECTOR BREAKDOWN

INDUSTRIAL SUBSECTORS CATEGORIES ARE BASED ON ENERGY CONSUMPTION, ECONOMICS, OTHER.

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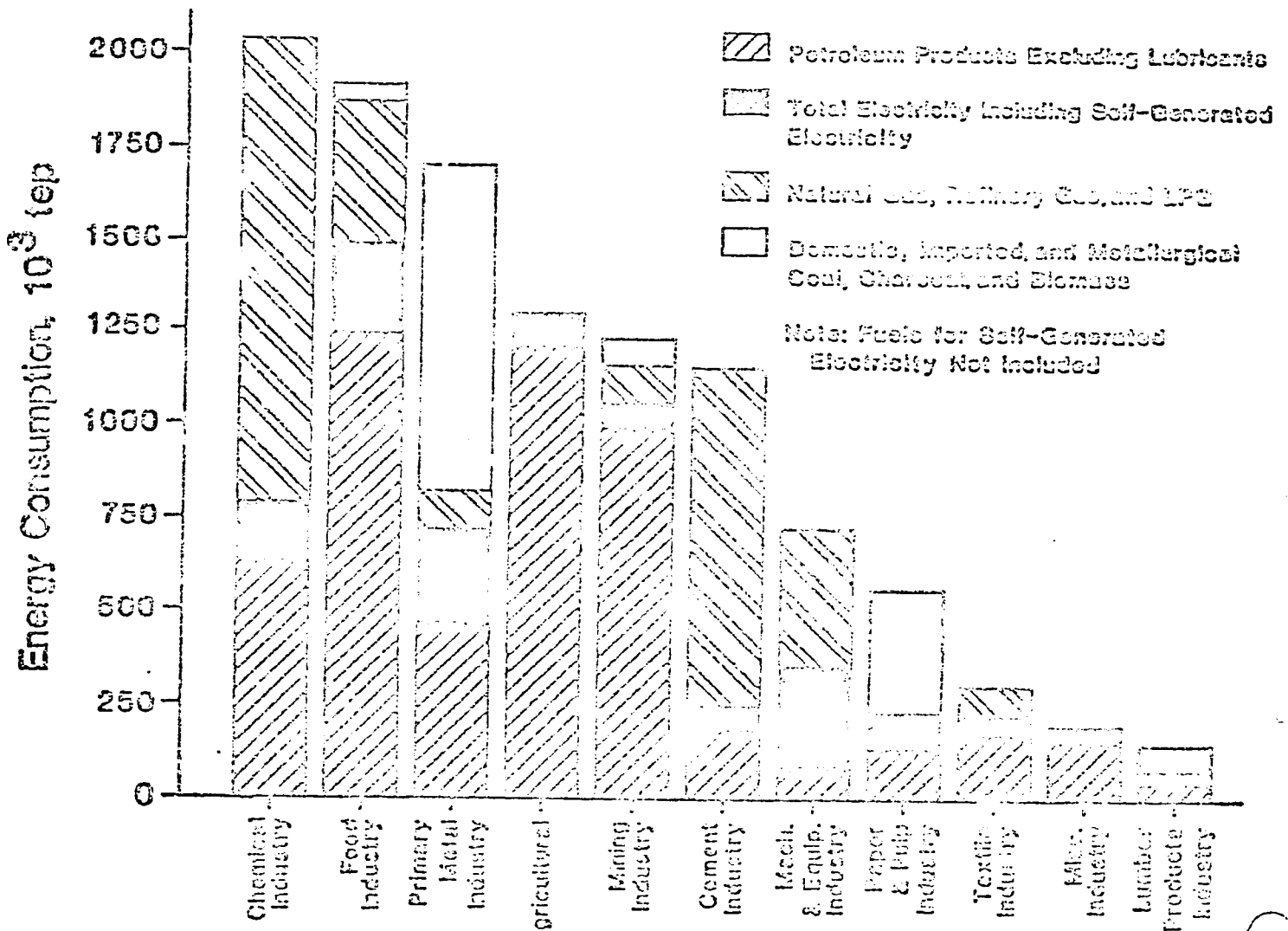
# 1978 INDUSTRIAL AND AGRICULTURAL SECTOR ENERGY CONSUMPTION

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TYPICAL INDUSTRIAL SUBSECTORS:

- CHEMICAL
- FOOD
- PRIMARY METAL
- MINING
- CEMENT
- MACHINERY AND EQUIPMENT
- PAPER AND PULP
- TEXTILE
- MISCELLANEOUS

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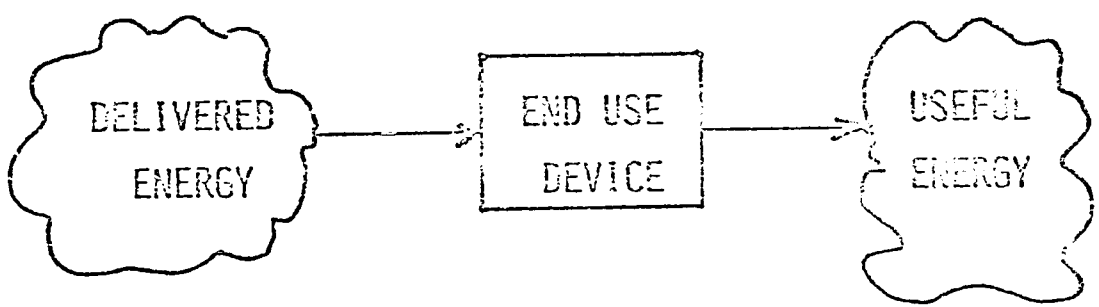
# DEFINITION OF END USE DEVICE

AN END USE DEVICE IS A PIECE OF HARDWARE OR PROCESS SYSTEM

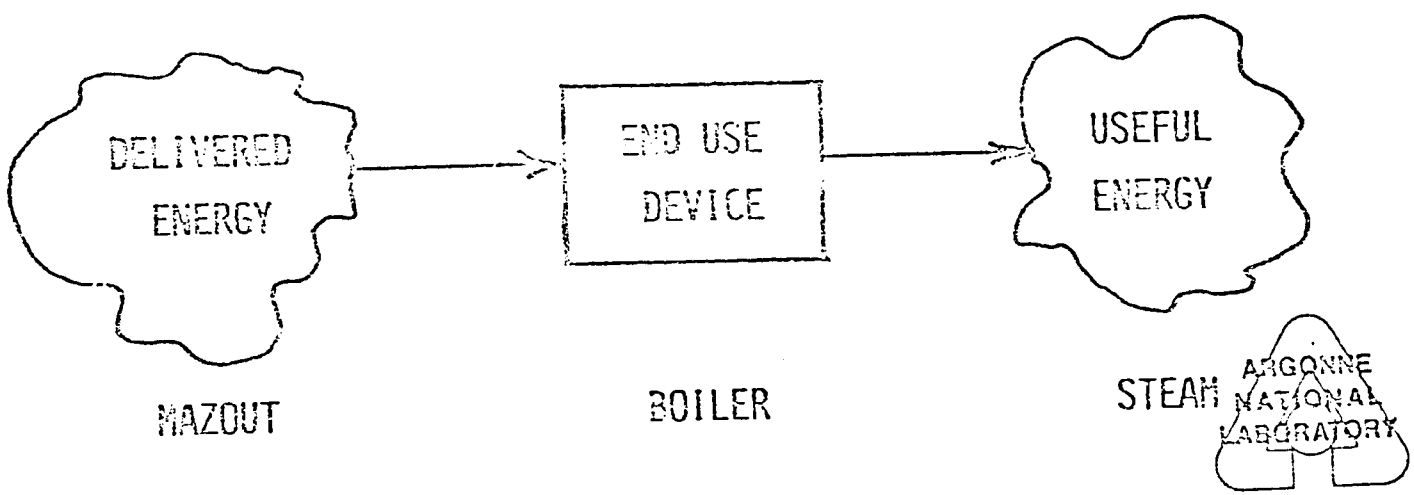
THAT CONVERTS ENERGY DELIVERED TO USEFUL ENERGY.



## DEFINITION OF USEFUL ENERGY

USEFUL ENERGY IS ENERGY IN ITS USEFUL FORM. IT IS ENERGY IN THE FORM OF:

- WORK
- LIGHT
- HEAT
- INTERNAL ENERGY TO PRODUCE CHEMICAL CHANGE

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IMPORTANCE OF END USE DEVICE.....

- ESTABLISHES OPPORTUNITY TO SWITCH OR SUBSTITUTE FUELS - FUEL SWITCHING

- IDENTIFIES OPPORTUNITY TO CHANGE PROCESS TO REDUCE ENERGY CONSUMPTION PER UNIT OF PRODUCTION - TECHNOLOGY CHANGE

- IDENTIFIES OPPORTUNITY TO INCREASE ENERGY EFFICIENCY OF EXISTING PROCESS - ENERGY CONSERVATION

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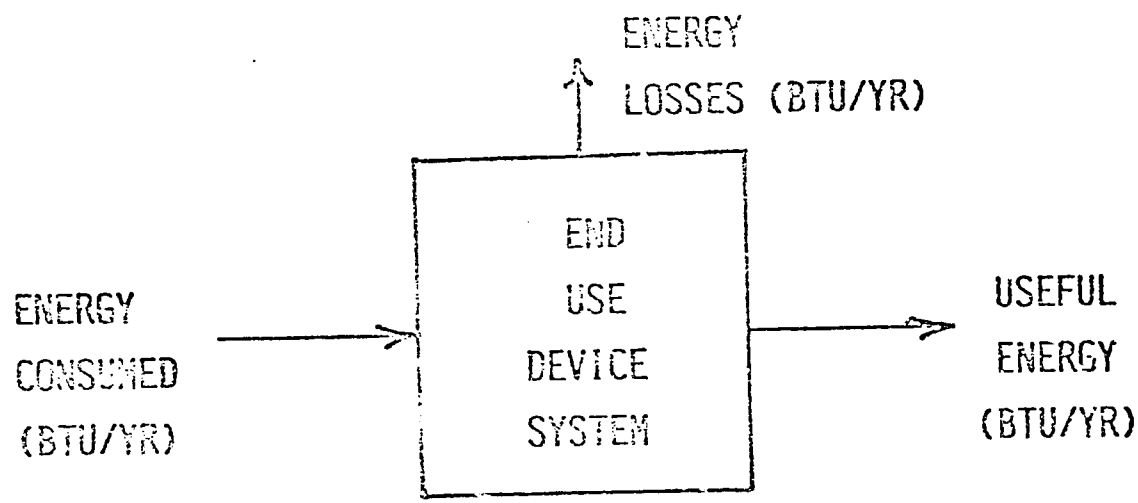
# CALCULATION OF USEFUL ENERGY




USEFUL ENERGY = ENERGY CONSUMED - ENERGY LOSSES

$$\text{DEVICE EFFICIENCY}\,(\eta) = \frac{\text{USEFUL ENERGY}}{\text{ENERGY CONSUMED}}$$

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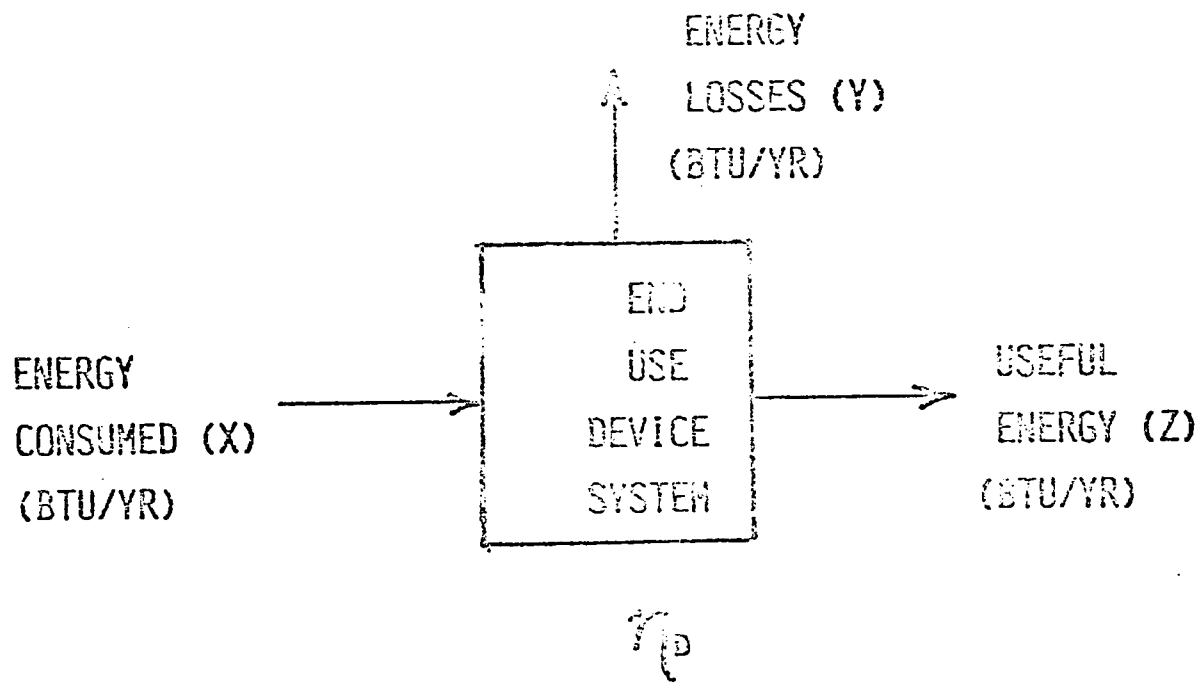
# EXERCISE ON CALCULATING USEFUL ENERGY




- IF X = 50 X $10^6$ BTU/YR HAZOUT AND Y = 20 X $10^6$ BTU/YR, FIND Z, $\eta_D$
- IF $\eta_D$ = .75 AND 30 X $10^6$ BTU/YR SOLAR ARE CONSUMED, WHAT IS USEFUL ENERGY? LOSSES?

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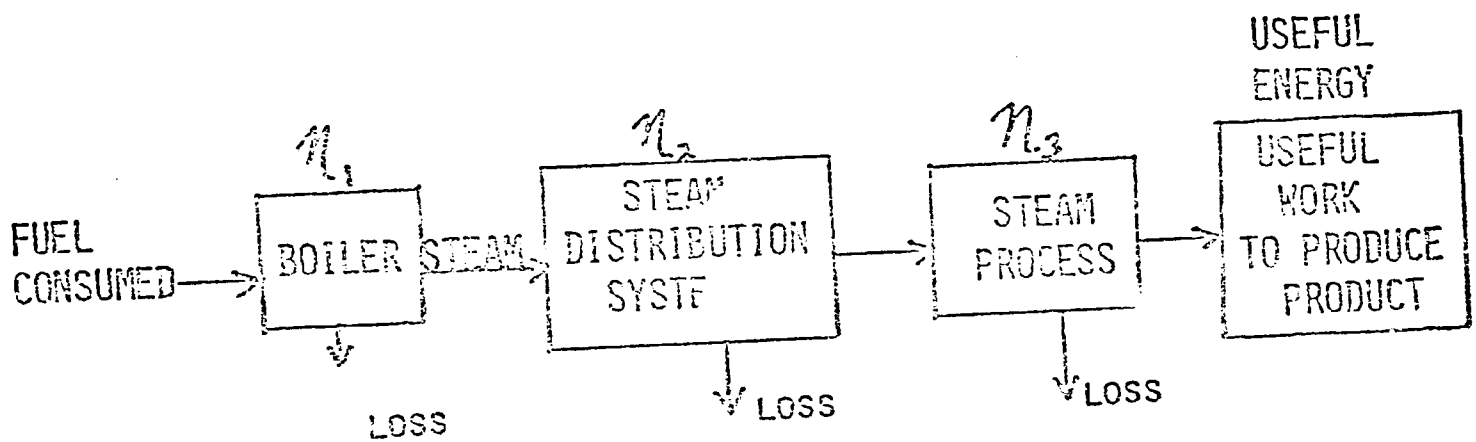
# END USE DEVICE SYSTEM




$\eta_i$ = THERMAL EFFICIENCY OF DEVICE

USEFUL ENERGY = FUEL CONSUMED $\times \eta_1 \times \eta_2 \times \eta_3$

OVERALL EFFICIENCY = $\eta_1 \times \eta_2 \times \eta_3$

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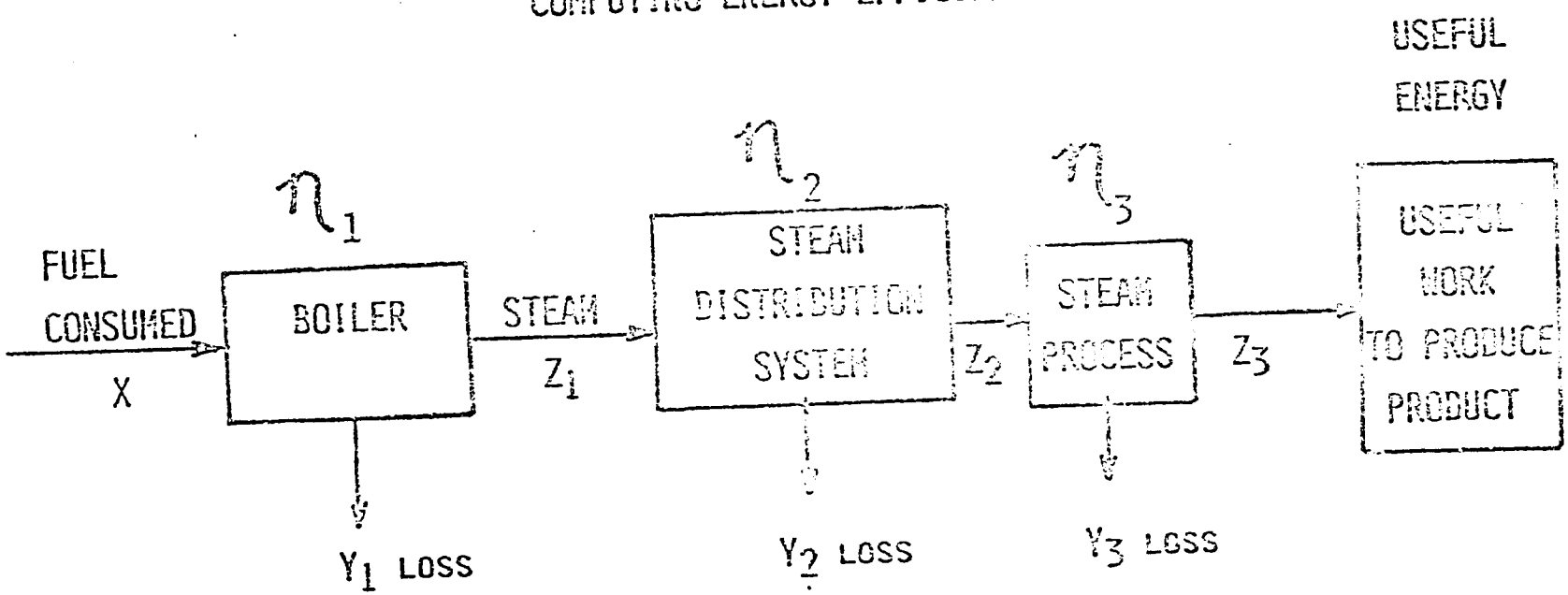
# END USE DEVICE SYSTEM
## COMPUTING ENERGY EFFICIENCY




- IF $X = 100 \times 10^6$ TEP NAZOUT AND $40 \times 10^6$ TEP ARE DELIVERED TO DRYER ($Z_3$), WHAT IS $Y_1 + Y_2 + Y_3$? WHAT IS $\eta_1 \times \eta_2 \times \eta_3$?

- IF $Y_3 = 10\%\ Z_2$, $Y_2 = 15\%\ Z_1$ AND $Y_1 = 25\%\ Z_1$, COMPUTE THE INDIVIDUAL DEVICE EFFICIENCIES AND OVERALL EFFICIENCY OF THE SYSTEM.

<u>NOTE</u>: X, Y AND Z ARE ENERGY FLOWS IN TEP/YR.

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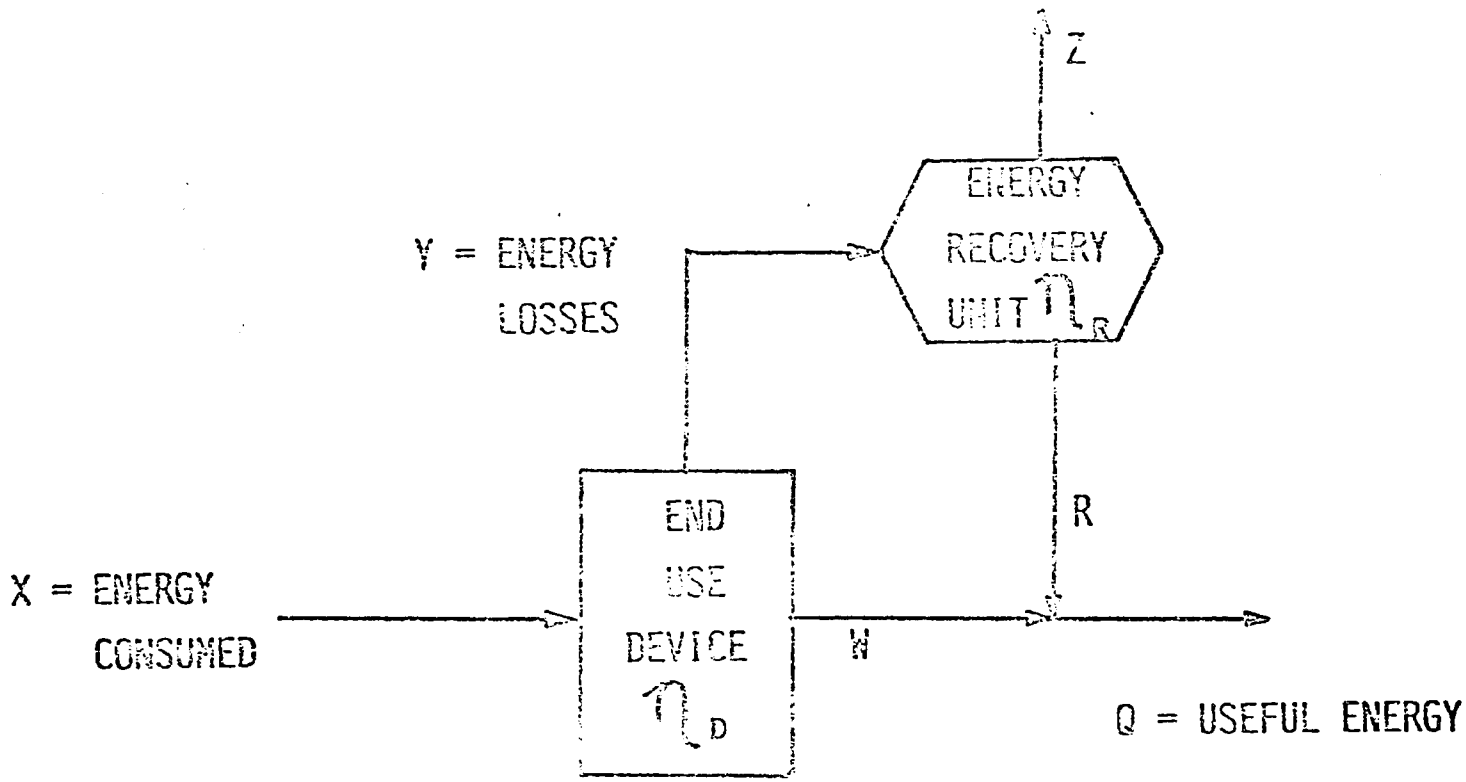
2

# IMPACT OF ENERGY CONSERVATION ON SYSTEM EFFICIENCY




- IF X = 40 X $10^6$ BTU/YR OF BUTANE AND $\eta_D$ = .80, WHAT IS USEFUL ENERGY W, AND ENERGY LOSSES Y?

- IF THE EFFICIENCY OF THE ENERGY RECOVERY UNIT, $\eta_R$ IS 40%, WHAT IS USEFUL ENERGY Q?

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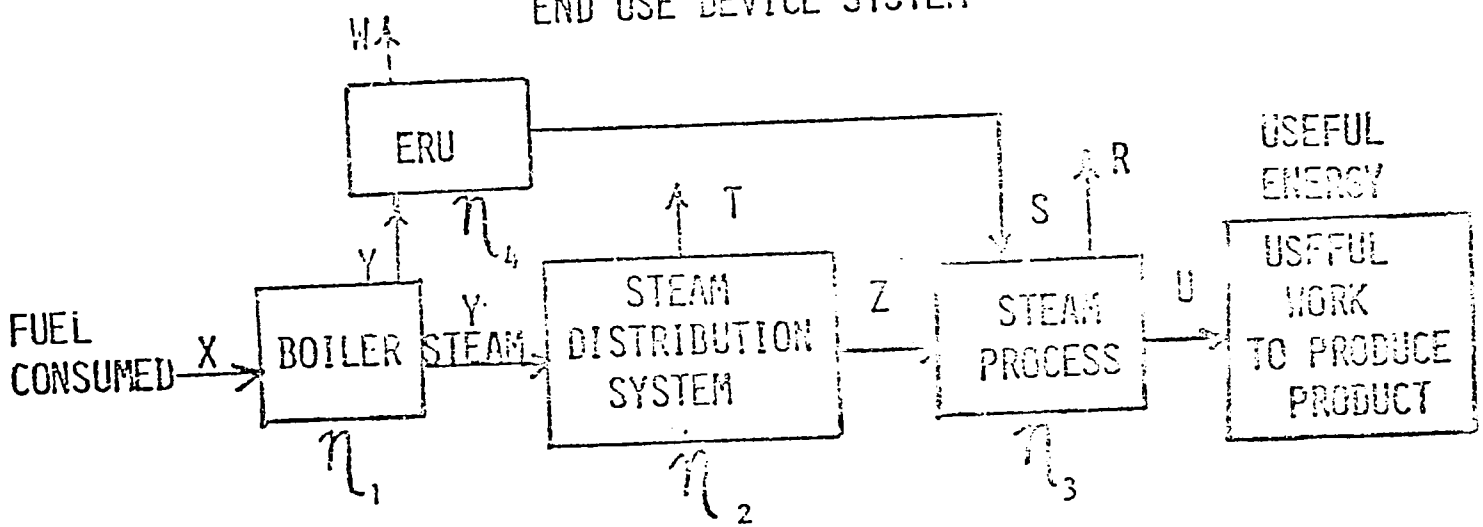
## ENERGY CONSERVATION
## END USE DEVICE SYSTEM




- IF X = 125 ($10^6$) TEP/YR, $\eta_1$ = 70%, $\eta_2$ = 90%, $\eta_3$ = 85% AND $\eta_4$ = 0, WHAT IS USEFUL ENERGY U? OVERALL SYSTEM EFFICIENCY $\eta_T$? WHAT IS Y, V, T, Z AND R?

- SAME AS ABOVE EXCEPT $\eta_4$ = 50%. WHAT IS S? WHAT IS $\eta_3$? WHAT IS U? WHAT IS $\eta_T$?

## COMPUTATION OF DEVICE USEFUL ENERGY

TO COMPUTE USEFUL ENERGY FROM A DEVICE YOU MUST SPECIFY:

- THE DEVICE OR DEVICE SYSTEM*
- THE OVERALL EFFICIENCY ($\eta$) OF THE DEVICE OR DEVICE SYSTEM
- THE TYPE AND QUANTITY OF ENERGY CONSUMED

*A DEVICE SYSTEM IS TWO OR MORE DEVICES THROUGH WHICH THE ENERGY FLOWS BEFORE BECOMING USEFUL ENERGY

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COMMONLY USED INDUSTRIAL DEVICES:

- DIRECT HEAT (CLEAN) - FLAME OR PRODUCTS OF COMBUSTION COME IN CONTACT WITH PRODUCT
- DIRECT HEAT - FURNACES, OVENS WHERE PRODUCT IS HEATED DIRECTLY
- INDIRECT HEAT - BOILERS, OIL HEATERS WHERE HEAT IS APPLIED TO HEAT EXCHANGE MEDIA SUCH AS WATER TO FORM STEAM
- DEDICATED ELECTRIC - MOTORS, LIGHTING, ELECTRIC FURNACES
- MECHANICAL POWER - CONVEYORS, MACHINERY
- NON-ENERGY - PETROLEUM PRODUCTS USED FOR OTHER PURPOSES THAN ENERGY -- PETROCHEMICAL FEEDSTOCK, GREASE, LUBRICANTS

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INDUSTRIAL DEVICE SYSTEMS...

- ARE MORE DIFFICULT TO DEFINE
- VARY CONSIDERABLY AMONG DIFFERENT TYPES OF INDUSTRY
- MAY VARY AMONG DIFFERENT PLANTS IN SAME INDUSTRY
- THE DEVICES IN A SYSTEM INCREASE IN IMPORTANCE WITH ENERGY LOSSES

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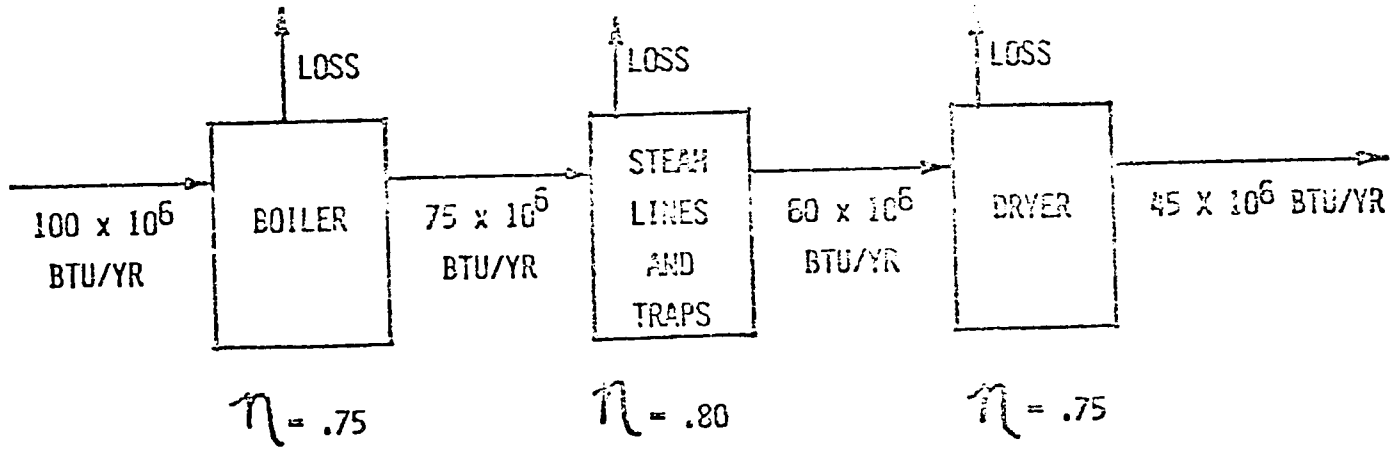
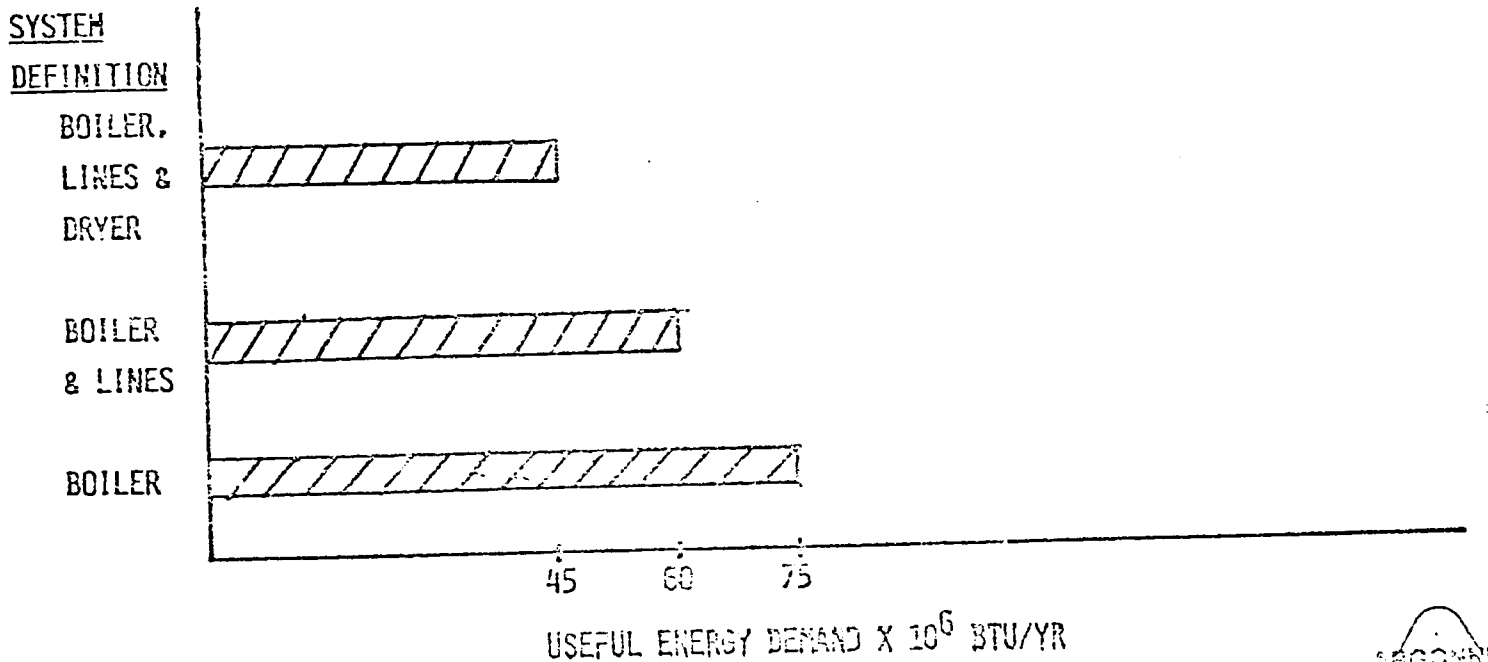
# BREAKDOWN OF DEVICE SYSTEM

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## USEFUL ENERGY DEMAND AND FUEL SWITCHING

THE CONCEPT OF USEFUL ENERGY DEMAND PERMITS AN EXAMINATION OF USING DIFFERENT FUELS OR FORMS OF ENERGY TO MEET THE DEMAND BECAUSE USEFUL ENERGY DEMAND IS NOT NECESSARILY CHARACTERIZED BY A SPECIFIC FUEL TYPE.

IT IS THEREFORE WORTHWHILE TO STRUCTURE THE SYSTEM TO EXAMINE THE FUEL SWITCHING POSSIBILITIES.

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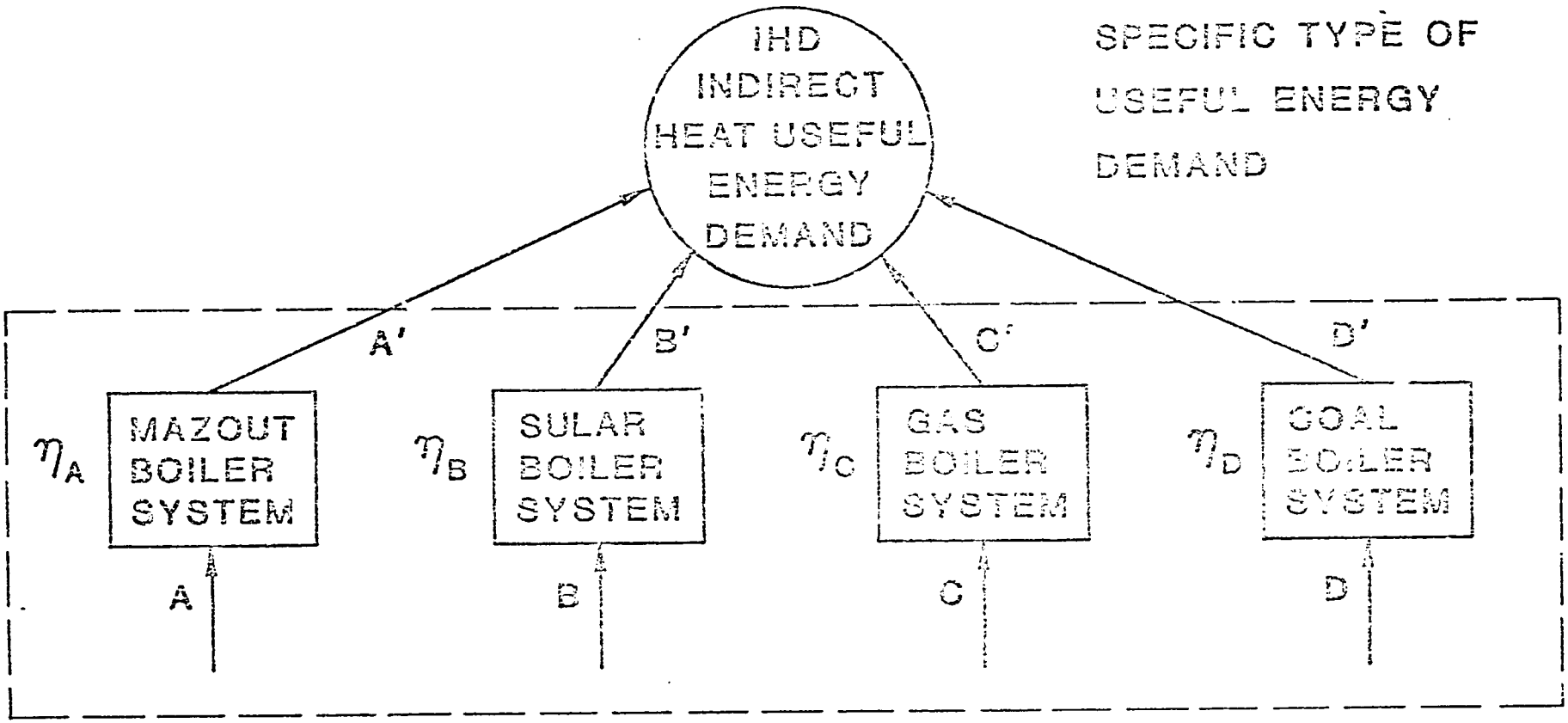
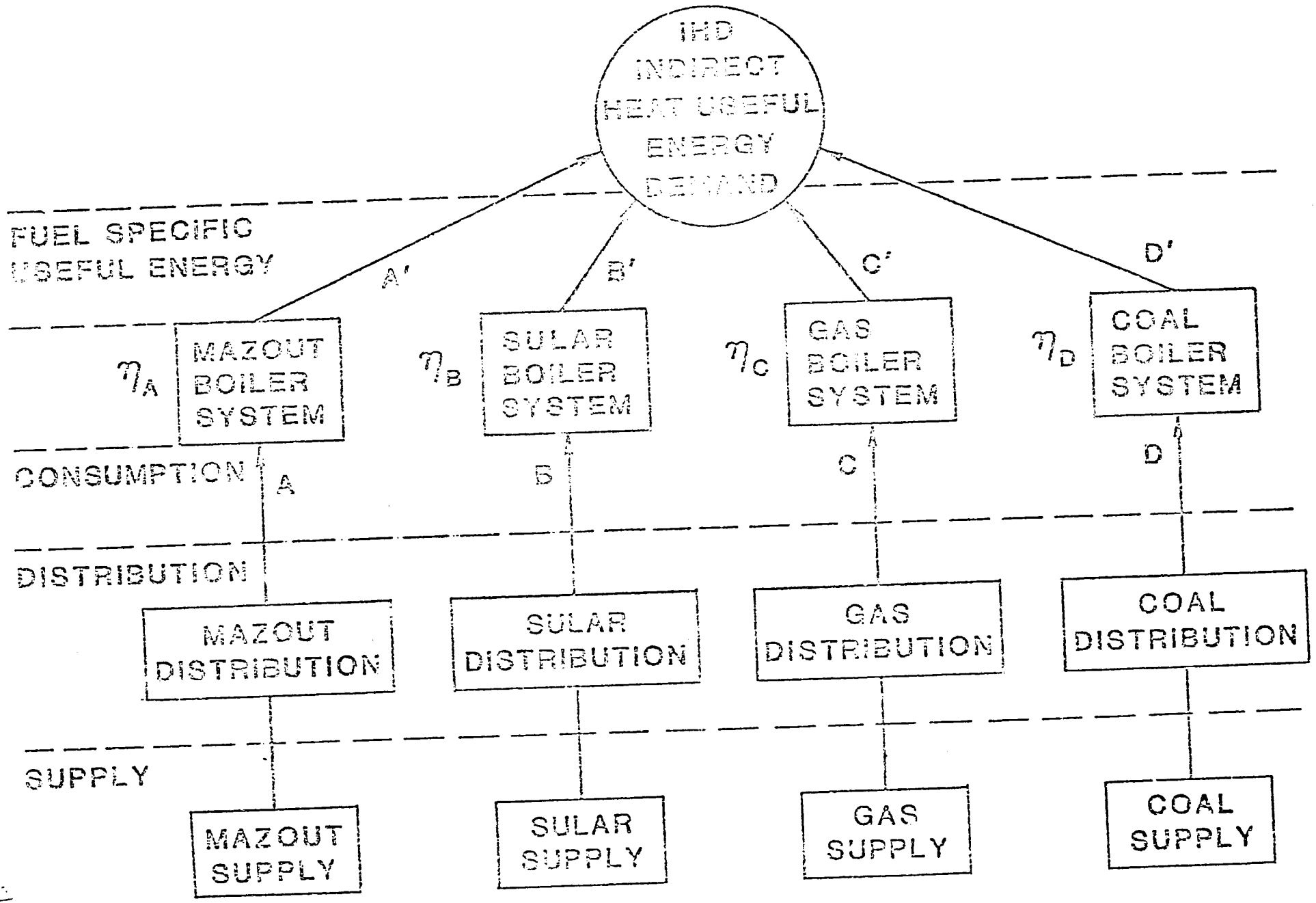
# DIFFERENT FUELS TO MEET ENERGY DEMAND

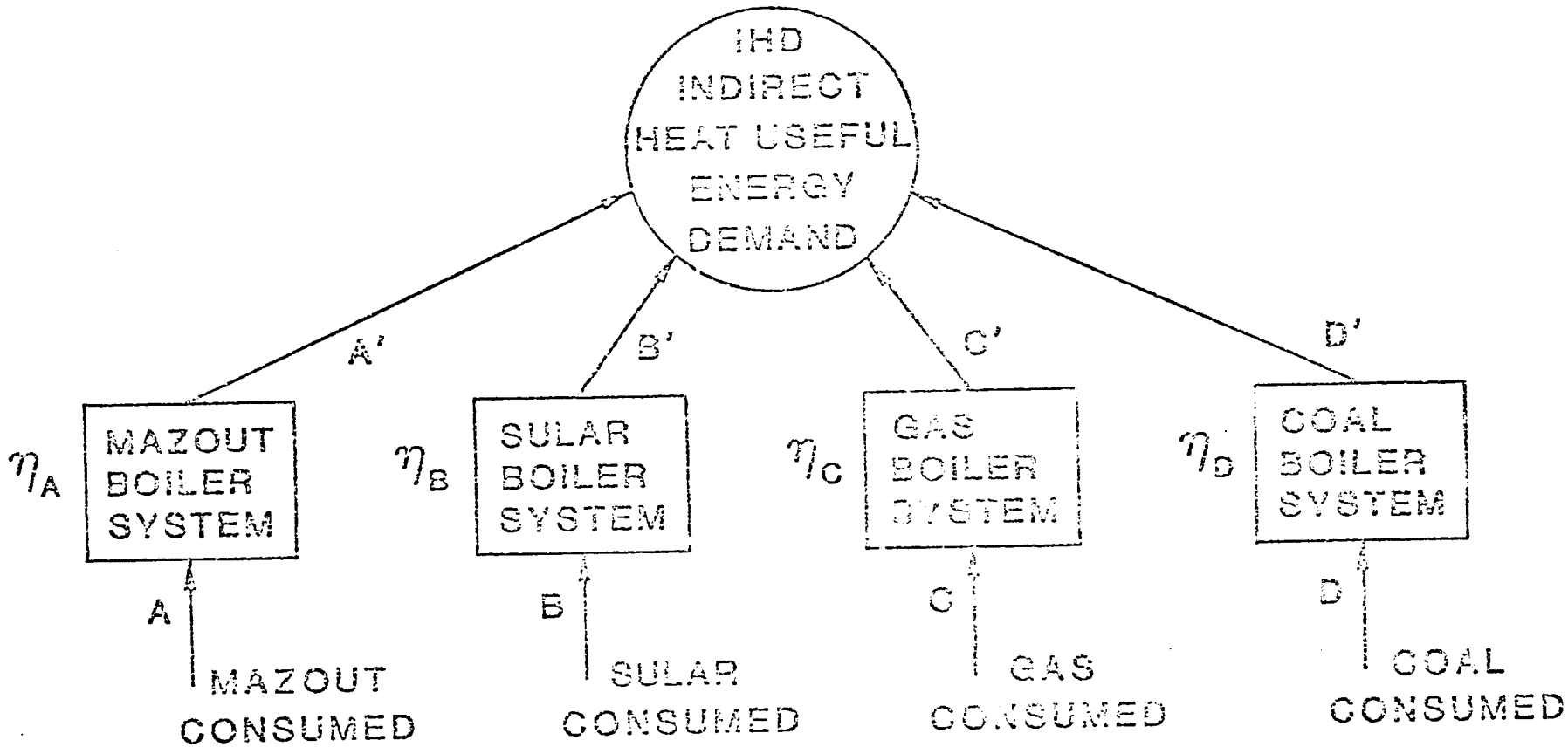



FUEL SPECIFIC
SYSTEMS THAT
COULD ACCOMODATE
THE USEFUL ENERGY
DEMAND

# DIFFERENT FUELS TO MEET ENERGY DEMAND



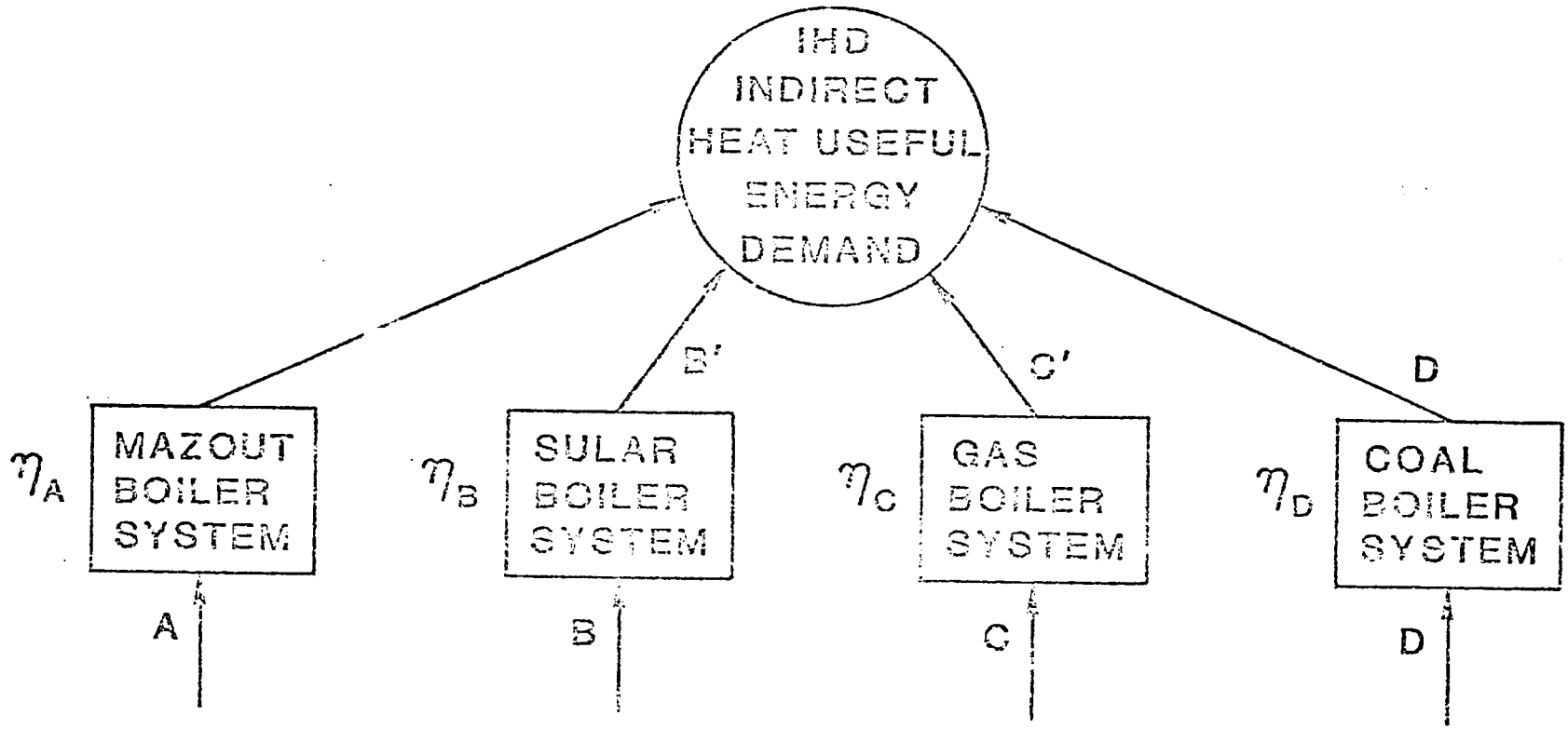
# DIFFERENT FUELS TO MEET ENERGY DEMAND




$$\text{IHD} = \begin{matrix}\text{INDIRECT}\\ \text{HEAT}\\ \text{USEFUL}\\ \text{ENERGY}\\ \text{DEMAND}\end{matrix} = \sum \begin{matrix}\text{USEFUL ENERGY FROM}\\ \text{ALL BOILERS}\end{matrix} = A + B + C + D$$

$$= \sum \eta_A A' + \eta_B B' + \eta_C C' + \eta_D D'$$

# COMPUTATION OF ENERGY DEMAND FROM DIFFERENT FUELS




- IF $A = 50 \times 10^6$ BTU/YR, $B = 40 \times 10^6$ BTU/YR, $C = 15 \times 10^6$ BTU/YR, $D = 5 \times 10^6$ BTU/YR, $\eta_A = 50\%$, $\eta_B = 70\%$, $\eta_C = 80\%$, $\eta_D = 75\%$
  WHAT IS THE TOTAL INDIRECT HEAT USEFUL ENERGY DEMAND (IHD)?

- WHAT IF C IS INCREASED BY 100% AND D IS INCREASED BY 50%
  WHAT HAPPENS TO A & B?

- HOW DO THE UNITS OF A,A', B,B', C,C', D,D', AND D,D' DIFFER FROM IHD?

## ...EXAMPLE OF BASE YEAR ENERGY DATA SET...

Table D-3 Base Year (1978) Industrial Energy Demand Data Food Industry ($10^3$ tep)[a]

| End-Use Device Energy Demand | Naphtha | Kerosene | Gas Oil | Diesel Fuel | Fuel Oil | Lubricants | Natural Gas | Biomass | Hydropower | Purchased Electricity[b] | Auto-Generated Electricity[b] | Total Electric[c] | Total Energy[e] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fuels and Other Energy Items | | | | | | | | | | | | |
| **INDIRECT HEAT** | | | | | | | | | | | | | |
| Consumption | 84.0 | 29.6 | 183.6 | 22.0 | 708.5 | | | 379.0 | | | | | 1406.7 |
| Efficiency[d] | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | | | 0.6 | | | | | 0.6 |
| Useful Energy[e] | 58.8 | 20.7 | 20.7 | 128.5 | 495.9 | | | 227.4 | | | | | 946.7 |
| **DIRECT HEAT - ANY FUEL** | | | | | | | | | | | | | |
| Consumption | | | 26.0 | | 191.8 | | | | | | | | 217.8 |
| Efficiency | | | 0.6 | | 0.6 | | | | | | | | 0.6 |
| Useful Energy | | | 15.6 | | 115.1 | | | | | | | | 130.7 |
| **DIRECT HEAT - CLEAN FUEL** | | | | | | | | | | | | | |
| Consumption | | | | | | | 46.0 | | | | | | 46.0 |
| Efficiency | | | | | | | 0.7 | | | | | | 0.7 |
| Useful Energy | | | | | | | 32.2 | | | | | | 32.2 |
| **MOTIVE POWER** | | | | | | | | | | | | | |
| Consumption | | | | | | 17.79 | | | | 72.59 | (28.43)[f] | (101.0) | 90.38 |
| Efficiency | | | | | | 1.0 | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| Useful Energy | | | | | | 17.79 | | | | 50.81 | (19.9) | (70.7) | 111.6 |
| **REFRIGERATION** | | | | | | | | | | | | | |
| Consumption | | | | | | | | | | 74.60 | (29.21) | (103.8) | 74.60 |
| Efficiency | | | | | | | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| Useful Energy | | | | | | | | | | 52.22 | (20.45) | (72.66) | 52.22 |
| **LIGHTING** | | | | | | | | | | | | | |
| Consumption | | | | | | | | | | 30.81 | (12.06) | (42.90) | 30.81 |
| Efficiency | | | | | | | | | | 0.2 | 0.2 | 0.2 | 0.2 |
| Useful Energy | | | | | | | | | | 6.16 | (2.41) | (8.58) | 6.16 |
| **AUTO-GENERATED ELECTRIC FUELS** | | | | | | | | | | | | | |
| Consumption | | | 74.0 | 22.0 | 36.9 | | 86.2 | 21.0 | (8) | | | | 240. |
| **TOTALS** | | | | | | | | | | | | | |
| Consumption | 84.0 | 29.6 | 283.6 | 44.0 | 937.2 | 17.79 | 132.2 | 400.0 | (8) | 176.0 | (69.7) | (247.7) | 2106.4 |
| Useful Energy | 58.8 | 20.7 | 144.1 | 15.4 | 611.0 | 17.79 | 32.2 | 227.4 | (8) | 109.19 | (42.76) | (151.94) | 1236.6 |

[a]1 tep = $1.05 \times 10^7$ KCAL = $4.393 \times 10^{10}$ Joules.

[b]N is Device Efficiency = Useful/Consumption

[c]Useful Energy = Energy Consumption x End Use Device Efficiency.

[d]Source Electric Demand Consumption has been adjusted so that distribution by end use device is the same for purchased electricity and auto-generated electricity.

[e]Total energy includes fuels used to produce auto-generated electricity and excludes the auto-generated electricity produced to avoid double counting.

[f]Numbers in parentheses not included in totals.

REVIEW ENERGY STRATEGY ISSUES...

- o FUEL SWITCHING OR SUBSTITUTION
- o CONVENTIONAL ENERGY CONSERVATION
  - REPLACING INEFFICIENT DEVICES
  - RECOVERING WASTE ENERGY FROM DELIVERED FUELS
- o SPECIAL ENERGY CONSERVATION ISSUES

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SPECIAL ENERGY CONSERVATION ISSUES

- o TECHNOLOGY CHANGE
- o CO-GENERATED AND SELF-GENERATED ELECTRICITY
- o ENERGY FROM SITE-GENERATED WASTE

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TECHNOLOGY CHANGE ISSUES...

- DIFFICULT TO CHARACTERIZE
  - MUST UNDERSTAND EXISTING DEVICE SYSTEM IN DETAIL
  - MUST UNDERSTAND NEW DEVICE SYSTEM IN DETAIL
- CHARACTERIZATION OF DEVICES MAY CHANGE
- ENERGY USE PATTERNS MAY CHANGE
- MUST BE PERFORMED AT THE INDUSTRY OR SUB-SECTOR LEVEL

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TECHNOLOGY CHANGE ISSUE

COMPARISON OF TOTAL ENERGY REQUIREMENTS FOR WET AND DRY PROCESS CEMENT[a]

| PROCESS | END USE DEVICE CATEGORY | WET PROCESS ENERGY ($10^3$ BTU/TONNE) | PERCENT OF TOTAL ENERGY | DRY PROCESS ENERGY ($10^3$ BTU/TONNE) | PERCENT OF TOTAL ENERGY |
|---|---|---|---|---|---|
| RAW MATERIAL PROCUREMENT | MECH. DRIVE | 53 | 0.7 | 60 | 1.1 |
| CRUSHING | ELECTROMOTIVE | 30 | 0.4 | 56 | 1.1 |
| GRINDING | ELECTROMOTIVE | 271 | 3.8 | 300 | 5.5 |
| PYROPROCESSING | DIRECT HEAT | 5705 | 79.2 | 3921 | 72.3 |
| CLINKER COOLING | ELECTROMOTIVE | 163 | 2.3 | 291 | 5.4 |
| FINISH GRINDING | ELECTROMOTIVE | 690 | 9.6 | 440 | 8.1 |
| PACKING AND HANDLING | ELECTROMOTIVE | 9 | 0.1 | 3 | 0.1 |
| AGGREGATED UTILITIES AND CONTROL | ELECTROMOTIVE | 27 | 0.4 | 83 | 1.5 |
| AGGREGATED MATERIALS USE | ELECTROMOTIVE | 31 | 0.4 | 43 | 0.8 |
| TRANSPORTATION OF FINISHED CEMENT | MECH. DRIVE | 225 | 3.1 | 225 | 4.1 |
| TOTAL | | 7204 | 100 | 5422 | 100 |

[a]ENERGY CONSUMPTION UNITS CONVERTED FROM MEGA JOULE/TONNE (952 BTU/MJ).

SOURCE: SAPP, J.E. "ENERGY AND MATERIALS FLOWS IN THE CEMENT INDUSTRY," ARGONNE NATIONAL LABORATORY, ANL/CNSV-17 (JUNE 1981).

...TECHNOLOGY CHANGE...

COMPARISON OF WET AND DRY PROCESS CEMENT

- BOTH THE WET AND DRY PROCESS USE THE SAME PROCESSES (E.G. END USE DEVICE SYSTEMS)

- DATA IS AVAILABLE ON THE ENERGY USE PER TONNE OF CEMENT PRODUCED (E.G. ENERGY INTENSITY)
  NOTE: NOT NECESSARILY USEFUL ENERGY PER TONNE OF CEMENT.

- THE DRY PROCESS REQUIRES LESS TOTAL ENERGY PER TONNE OF CEMENT THAN THE WET PROCESS (E.G. 7204 - 5422, OR 1782 X $10^3$ BTU/TONNE -- A 25% REDUCTION IN ENERGY DEMAND).

- THE ELECTRIC USE FOR BOTH PROCESSES IS ABOUT THE SAME (WET - 1221 X $10^3$ BTU/TONNE, DRY - 1226 X $10^3$ BTU/TONNE).

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## ...TECHNOLOGY CHANGE...

### COMPARISON OF WET AND DRY PROCESS CEMENT

- THE TECHNOLOGY CHANGE BETWEEN THE WET AND DRY PROCESS COMES FROM THE REDUCED USE OF WATER IN THE DRY PROCESS.

- IN THE PYROPROCESSING STAGE (e.g. DIRECT HEAT) $5705 \times 10^3$ BTU/TONNE IS CONSUMED IN THE WET PROCESS AND ONLY $3921 \times 10^3$ BTU/TONNE IN THE DRY PROCESS - A REDUCTION OF $1784 \times 10^3$ BTU/TONNE.

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## ...TECHNOLOGY CHANGE...

### COMPARISON OF WET AND DRY PROCESS CEMENT

- NOTE THAT THE PYROPROCESSING STAGE IS A DIRECT-FIRED FURNACE (E.G. ROTARY KILN) FOR BOTH THE WET AND DRY PROCESS.

- THE EFFICIENCY OF THE FURNACE IS THE SAME FOR BOTH THE WET AND DRY FURNACE.

- THE MATERIAL DEMANDING THE USEFUL ENERGY IS DIFFERENT

  - WET PROCESS - SLURRY OF AGGREGATE AND WATER

  - DRY PROCESS - DRY AGGREGATE

- MORE ENERGY IS REQUIRED IN THE WET PROCESS TO EVAPORATE THE WATER

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TECHNOLOGY CHANGE ISSUE - CONT'D

COMPARISON OF WET AND DRY PROCESS
END USE DEVICE ENERGY CONSUMPTION

| AGGREGATED END USE DEVICE CATEGORY | ENERGY CONSUMPTION ($10^3$ BTU/TONNE) | | | | % CHANGE WET TO DRY |
|---|---|---|---|---|---|
| | WET PROCESS | % OF TOTAL ENERGY | DRY PROCESS | % OF TOTAL ENERGY | |
| MECHANICAL DRIVE | 278 | 3.86 | 285 | 5.26 | 2 |
| ELECTROMOTIVE | | | | | |
| CRUSHING AND GRINDING | 991 | 13.76 | 797 | 14.70 | -20 |
| CLINKER COOLER (MOTOR & FAN) | 163 | 2.26 | 291 | 5.37 | 80 |
| MISCELLANEOUS | 67 | 0.93 | 129 | 2.38 | 93 |
| DIRECT HEAT | 5705 | 79.19 | 3921 | 72.30 | -31 |
| TOTAL | 7204 | 100 | 5423 | 100 | -25 |

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## ...TECHNOLOGY CHANGE...

### COMPARISON OF WET AND DRY PROCESS CEMENT

- THE BEST WAY TO HANDLE A TECHNOLOGY CHANGE ISSUE IS TO REPLACE THE OLD TECHNOLOGY WITH THE NEW TECHNOLOGY IN SOME FUTURE YEAR, AND

- BREAK DOWN THE NEW TECHNOLOGY INTO THE APPROPRIATE END USE DEVICE SYSTEM, WORKING <u>BACKWARD</u> FROM THE TOTAL NEW ENERGY CONSUMPTION BASED ON PRODUCTION.

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# TECHNOLOGY CHANGE ISSUE

## PROJECT TECHNOLOGY CHANGE

| 1980 | | 1990 | | DRY PROCESS ENERGY CONSUMPTION |
|---|---|---|---|---|
| BASE YEAR CEMENT PRODUCTION | PROJECT → | FUTURE YEAR CEMENT PRODUCTION | → | TOTAL PLANT ENERGY CONSUMPTION |
| 59,000 TONNE/YR | | 64,000 TONNE/YR | | 64,000 TONNE/YR<br>X 5423 ($10^3$)BTU/TONNE<br>= .347 X $10^{12}$ BTU/YR |

TECHNOLOGY CHANGE ISSUE - CONT'D

FUTURE YEAR DRY PROCESS CEMENT PLANT ENERGY CONSUMPTION

| END USE DEVICE CATEGORY | % OF PLANT ENERGY CONSUMPTION | ENERGY CONSUMPTION FUEL | ENERGY CONSUMPTION ($10^3$) BTU/YR | END USE DEVICE EFFICIENCY | USEFUL ENERGY ($10^3$) BTU/YR |
|---|---|---|---|---|---|
| MECHANICAL DRIVE | 15.26 | DIESEL | 18.25 | .30 | 5.48 |
| ELECTROMOTIVE | | ELECTRIC | | | |
| CRUSHING & GRINDING | 14.70 | | 51.01 | .60 | 30.61 |
| CLINKER COOLER (MOTOR AND FAN) | 5.37 | | 18.63 | .70 | 13.04 |
| MISCELLANEOUS | 2.38 | | 8.26 | .50 | 4.13 |
| DIRECT HEAT | 72.30 | FUEL OIL | 250.88 | .20 | 50.18 |
| TOTAL | 100 | | 347 | | |

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...REVIEW...

TECHNOLOGY CHANGE ISSUE

- END USE DEVICES MAY CHANGE
- MUST TRANSLATE CONVENTIONAL PROCESS TO NEW PROCESS
- PROJECT PRODUCTION LEVEL OVER TIME
- CONSTRUCT NEW SET OF DEVICES AND/OR EFFICIENCIES
- COMPUTE ENERGY CONSUMPTION
- COMPUTE USEFUL ENERGY
- PERFORM FUEL SWITCH AS SEPARATE STRATEGY

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## SITE (SELF) GENERATED ELECTRICITY ISSUE

- SITE-GENERATED ELECTRICITY IS ELECTRICITY GENERATED IN THE DEMAND SECTOR FROM A FUEL DELIVERED FROM THE SUPPLY SECTOR. THEREFORE, IN A SUPPLY-DEMAND ANALYSIS FRAMEWORK THE END-USE DEVICE SYSTEM REQUIRES A SPECIAL TREATMENT.

- A FURTHER COMPLICATION OF SITE-GENERATED ELECTRICITY IS THAT IT MUST BE COMBINED WITH SUPPLY SECTOR (E.G. UTILITY) ELECTRICITY TO MEET TOTAL ELECTRIC DEMAND (I.E. THE ELECTRIC MOTOR DOES NOT KNOW OR CARE IF THE ELECTRICITY WAS SUPPLIED BY THE UTILITY OR GENERATED ON-SITE).

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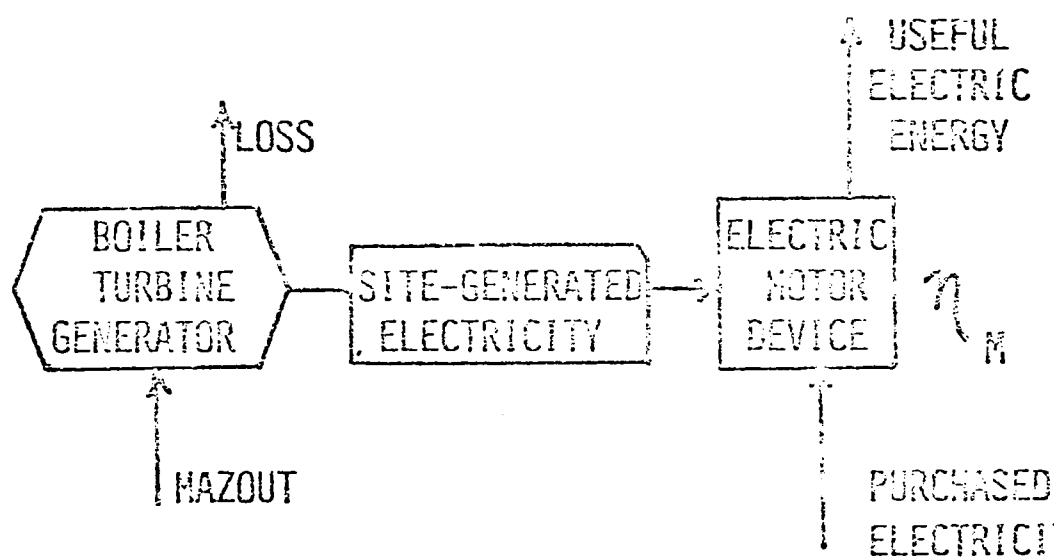
## SELF (SITE)-GENERATED ELECTRICITY ISSUE

- PLANTS CAN SUPPLY THE FOLLOWING INFORMATION:
  - FUEL CONSUMED AND ELECTRICITY PRODUCED BY SITE GENERATION
- ELECTRICITY PURCHASED FROM THE UTILITY
- INFORMATION ON DEVICES THAT CONSUME ELECTRICITY (E.G. MOTORS, LIGHTS)
- THE END-USE DEVICE SYSTEM MODEL FOR THIS ARRANGEMENT IS ILLUSTRATED AS FOLLOWS:

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## DISTRIBUTION OF SITE-GENERATED ELECTRIC

- COMPUTE % DISTRIBUTION OF PURCHASED ELECTRIC DEMAND TO ALL DEVICES (e.g. 2% LIGHTING, 70% MOTOR/COMPRESSOR, 28% MOTOR/PUMP).
- USE SAME % DISTRIBUTION FOR SITE-GENERATED ELECTRIC.
- MAINTAIN SEPARATE ACCOUNT OF SITE-GENERATED FUEL USE FOR ELECTRIC PRODUCTION.
- FOR LARGE SITE-GENERATORS, TRACK SELF-GENERATED ELECTRIC SOLD.

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## BASE YEAR SITE-GENERATED ELECTRIC

| FUELS | FUEL CONSUMPTION ($10^9$ BTU/YR) | EFFICIENCY | ELECTRIC CONSUMPTION TOTAL CONSUMED - SOLD |
|---|---|---|---|
| DIESEL | 30 | .40 | $12 \times 10^9$ BTU<br>$3.5 \times 10^6$ KWH |
| FUEL OIL | 60 | .30 | $18 \times 10^9$ BTU<br>$5.3 \times 10^6$ KWH |
| SUB-TOTAL | | | $30 \times 10^9$ BTU<br>$8.8 \times 10^6$ KWH |
| SITE-GENERATED WOOD | 20 | .20 | $4 \times 10^9$ BTU<br>$1.17 \times 10^6$ KWH |

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FUTURE YEAR SITE-GENERATED ELECTRIC OPTIONS

- REDUCE SITE-GENERATED ELECTRIC
- CONVERT TO COGENERATED ELECTRIC MODE

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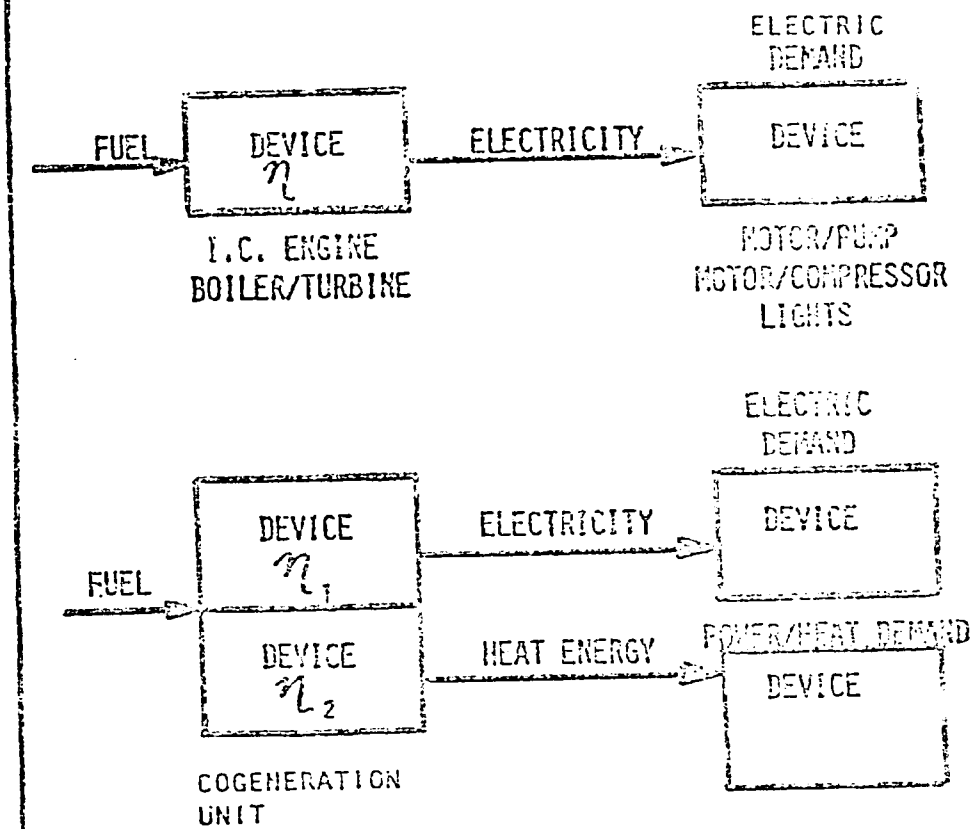
# ELECTRICITY

## SITE-GENERATED VS COGENERATED




SITE-GENERATED

ELECTRIC REDUCES DEMAND FROM ELECTRIC UTILITY.

DEMAND ACCOUNTED FOR BY SUPPLY SECTOR FUELS.

COGENERATED

ENERGY REDUCES DEMAND FROM ELECTRIC UTILITY AND REDUCES SUPPLY SECTOR FUELS DEMANDED FOR HEAT AND POWER.

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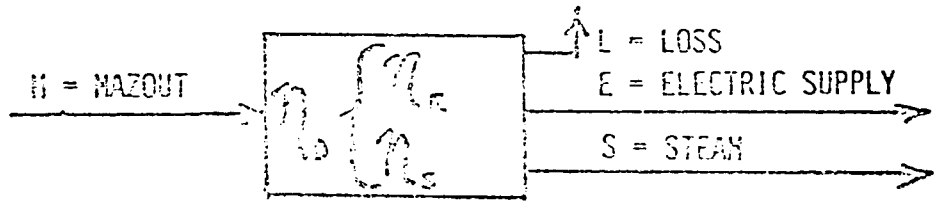
# COGENERATION ENERGY ANALYSIS




- ENERGY BALANCE

$$M = L + E + S$$

- COGENERATION EFFICIENCY

$\eta_o$ = OVERALL EFFICIENCY = $\frac{E + S}{M}$

$\eta_E$ = EFFICIENCY OF ELECTRICITY PRODUCTION = $\frac{E}{M}$

$\eta_S$ = EFFICIENCY OF STEAM PRODUCTION = $\frac{S}{M}$

- FUNCTIONAL RELATIONSHIP BETWEEN ELECTRIC AND STEAM PRODUCED

$E = A'S$ A′ REPRESENTS FUNCTIONAL RELATIONSHIP

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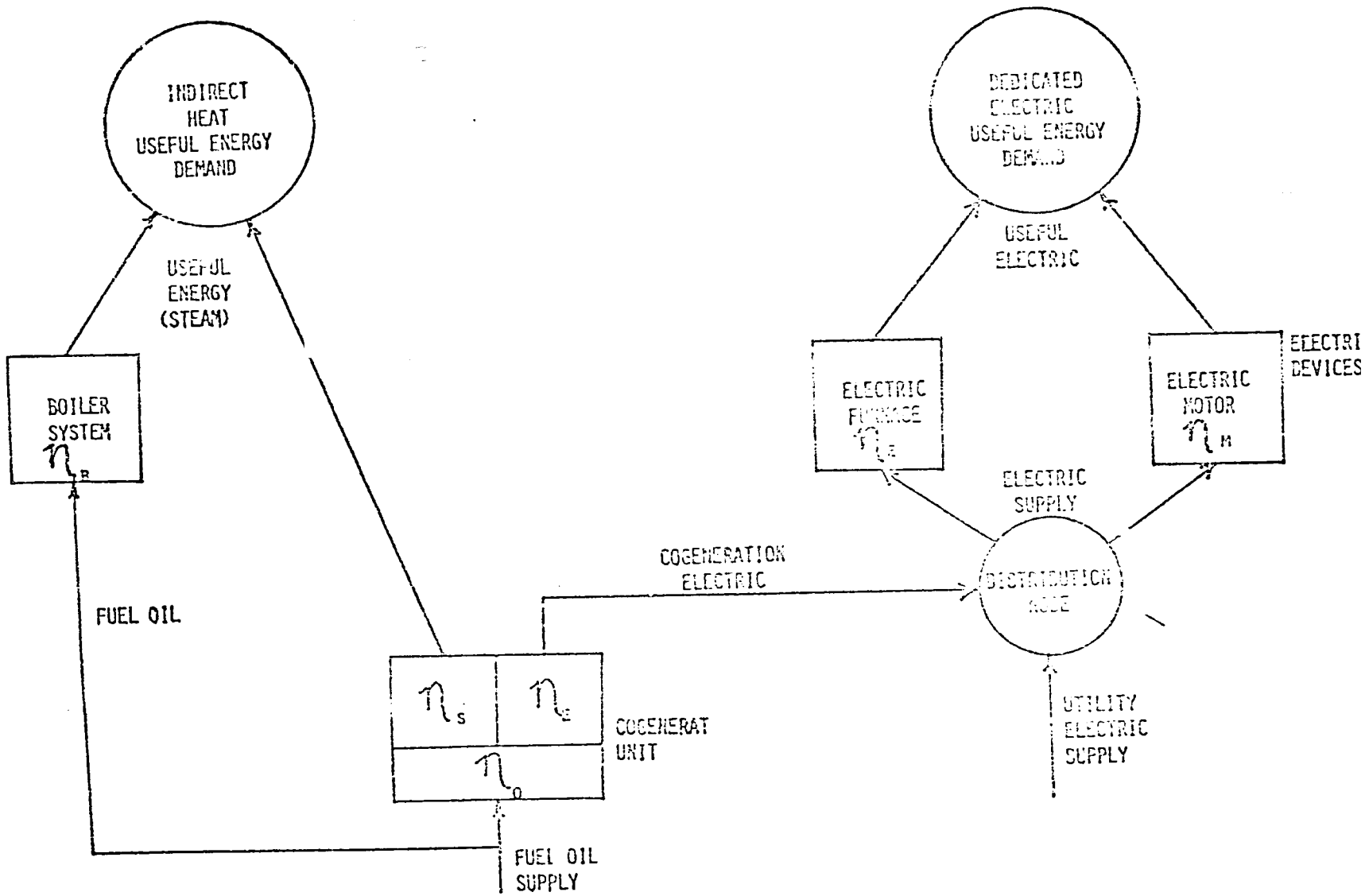
# COGENERATION NETWORK



## SITE-GENERATED WASTE FOR ENERGY

- SITE-GENERATED WASTE IS WASTE MATERIAL GENERATED AT A PLANT SITE THAT CAN BE USED AS A FUEL.

- EXAMPLES OF SUCH WASTE ARE:
  - PLASTICS
  - PAPER, CARDBOARD AND WOOD
  - BAGASSE FROM SUGAR CANE
  - GENERAL AGRICULTURAL WASTE

- RECOGNIZING THE AVAILABILITY OF UTILIZING WASTE FUEL CAN REDUCE THE DEMAND OF CONVENTIONAL ENERGY FROM THE SUPPLY SECTOR.

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## SITE-GENERATED WASTE FOR ENERGY

- o DETERMINE TYPE, HEAT CONTENT AND AVAILABILITY
- o ASSIGN FUELS TO DEVICES
- o REDUCE ENERGY DEMAND FROM SUPPLY SECTOR BY AMOUNT GENERATED FROM WASTE

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## ECONOMIC DATA SET FOR ENERGY ANALYSIS

- SEVERAL ISSUES AFFECTING ENERGY DEMAND ANALYSIS HAVE BEEN EXAMINED FROM A TECHNICAL PERSPECTIVE:

  - FUEL SWITCHING OR SUBSTITUTION

  - CONVENTIONAL ENERGY CONSERVATION

    REPLACING OLD DEVICES WITH NEW DEVICES

    ADD ON WASTE ENERGY RECOVERY UNITS

  - TECHNOLOGY CHANGE

    REPLACING EXISTING PROCESSES WITH MORE ENERGY-EFFICIENT PROCESSES

    COGENERATION

- THESE ISSUES MUST ALSO BE EXAMINED FROM AN ECONOMIC PERSPECTIVE

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## ECONOMICS OF FUEL SWITCHING OR SUBSTITUTION

- FROM A TECHNICAL PERSPECTIVE, THE DESIRABILITY OF USING A PARTICULAR FUEL TO MEET AN END-USE DEMAND IS BASED ON THE RELATIVE DEVICE EFFICIENCY OF CONVERTING THE FUEL TO USEFUL ENERGY (E.G. COMPARISON OF COAL BOILER TO GAS BOILER).

- FROM AN ECONOMIC PERSPECTIVE, THE DESIRABILITY OF SELECTING A FUEL (AND FUEL-SPECIFIC) DEVICE IS BASED ON THE FOLLOWING:

  - CAPITAL COST OF FUEL-SPECIFIC DEVICE

  - NON-FUEL OPERATING AND MAINTENANCE COST

  - COST OF FUEL

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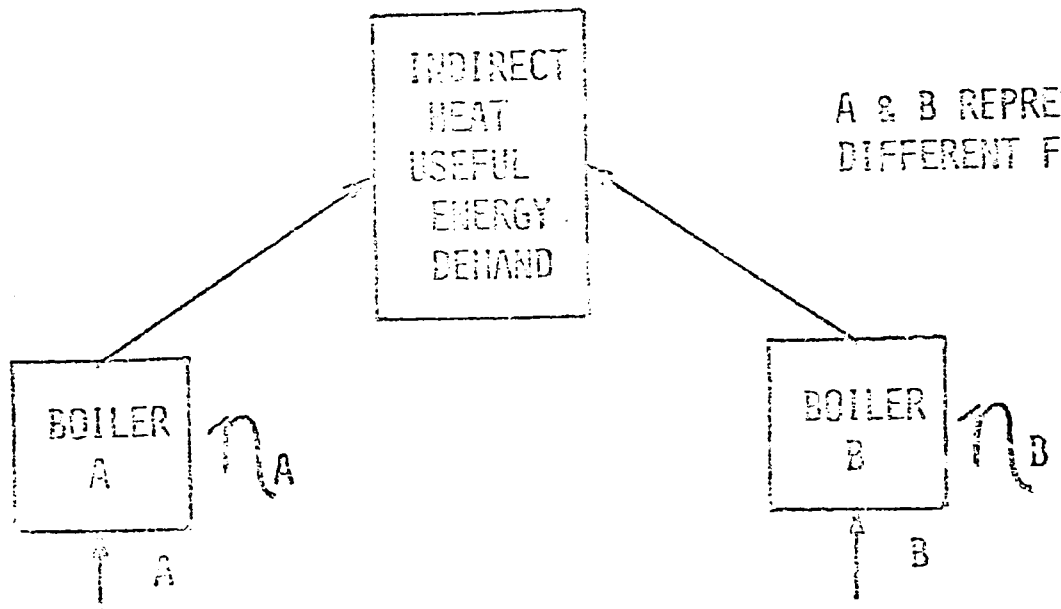
## ECONOMICS OF FUEL SWITCHING OR SUBSTITUTION




A & B REPRESENT DIFFERENT FUELS

- TECHNICAL DATA SET

  $\eta_A > \eta_B$ BOILER A IS MORE ENERGY EFFICIENT THAN BOILER B

- ECONOMIC DATA SET
  - THE INSTALLED CAPITAL COST OF BOILER A IS GREATER THAN BOILER B
  - THE COST OF FUEL A (L.E./BTU) IS LESS THAN FUEL B
  - THE ANNUAL OPERATING AND MAINTENANCE COST OF BOILER A IS LESS THAN BOILER B

- WHICH USEFUL ENERGY COST (L.E./USEFUL BTU) IS LESS?

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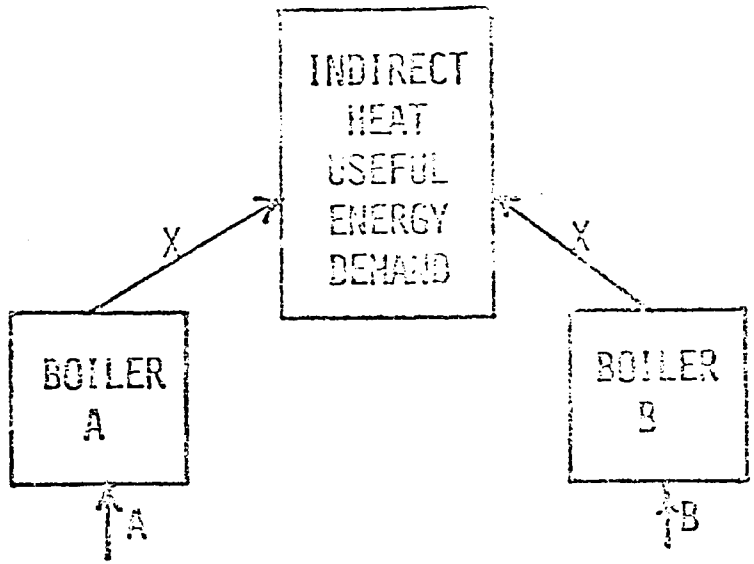
# ECONOMICS OF FUEL SWITCHING OR SUBSTITUTION




COMPARISON OF TWO DIFFERENT FUEL DEVICES TO MEET DEMAND

- TECHNICAL DATA SET

  $\eta_A = .80$ $\eta_B = .65$ $X = 5 \times 10^{10}$ BTU/YR USEFUL ENERGY DEMAND

- ECONOMIC DATA SET
  - ANNUALIZED, INSTALLED CAPITAL COST

    $C_A = 3 \times 10^5$ L.E./YR $C_B = 2 \times 10^5$ L.E./YR
  - ANNUAL NON-FUEL OPERATING AND MAINTENANCE COST

    $A_A = 5 \times 10^5$ L.E./YR $A_B = 10 \times 10^5$ L.E./YR
  - FUEL COST

    $F_A = 5$ L.E./$10^6$ BTU $F_B = 3$ L.E./$10^6$ BTU

- WHAT IS ANNUAL TOTAL COST FOR EACH SYSTEM TO MEET THE USEFUL ENERGY DEMAND ($5 \times 10^{10}$ BTU/YR)?

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## ...USEFUL ENERGY PROJECTIONS...

- IN THE SUPPLY-DEMAND ANALYSIS, FUTURE YEAR CHANGES IN ENERGY DEMAND ARE FIRST CHARACTERIZED BY CHANGES IN USEFUL ENERGY DEMAND THAT IS LATER CONVERTED TO ENERGY CONSUMED (E.G. DELIVERED BY THE SUPPLY SECTOR).

- USEFUL ENERGY DEMAND IS REPRESENTED BY CERTAIN MUTUALLY DISTINCT CATEGORIES THAT REFLECT HOW THE ENERGY IS UTILIZED SUCH AS:

  - DIRECT HEAT (CLEAN FUEL)
  - DIRECT HEAT (ANY FUEL)
  - INDIRECT HEAT
  - DEDICATED ELECTRIC
  - NONENERGY FEEDSTOCK

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## ...USEFUL ENERGY PROJECTION...

$$\left(\begin{array}{c}\text{BASE YEAR}\\ \text{INDIRECT HEAT}\\ \text{USEFUL ENERGY}\\ \text{DEMAND}\end{array}\right) \times \left(\begin{array}{c}\text{GROWTH}\\ \text{FACTOR}\end{array}\right) = \begin{array}{c}\text{FUTURE YEAR}\\ \text{INDIRECT HEAT}\\ \text{USEFUL ENERGY}\\ \text{DEMAND}\end{array}$$

- GROWTH FACTORS ARE TYPICALLY TIED TO ECONOMIC PREDICTIONS OF A COUNTRY'S ESTIMATION OF AN INCREASE IN GNP.
- THE BEST TYPE OF GROWTH FACTOR IS ONE THAT IS DIRECTLY APPLICABLE TO A SPECIFIC TYPE OF PRODUCTION (E.G. TONNES OF CEMENT/YR).
- IF THERE IS NO RADICAL TECHNOLOGY CHANGE, THE USEFUL ENERGY/TONNE OF PRODUCT REMAINS CONSTANT WITH TIME (REMEMBER, USEFUL ENERGY DOES NOT HAVE THE ATTRIBUTES OF FUEL TYPE OR EFFICIENCY OF THE PROCESS).

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...USEFUL ENERGY PROJECTION...

FUTURE YEAR USEFUL AND SUPPLIED ENERGY

---EXAMPLE PROBLEM---

- BASE YEAR (1980) CEMENT PRODUCTION IS 60,000 TONNE/YR. BY 1990 THE PRODUCTION IS EXPECTED TO INCREASE BY 10%. THE BASE YEAR KILN EFFICIENCY IS 60%. THE KILN CONSUMED $416.67 \times 10^9$ BTU OF MAZOUT IN 1980. BETWEEN 1980 AND 1990 THE EFFICIENCY OF THE KILN WAS INCREASED BY 10% USING WASTE HEAT RECOVERY MEASURES:

  - WHAT IS THE ANNUAL USEFUL ENERGY DEMANDED BY THE KILN IN 1990?

  - WHAT IS THE ANNUAL CONSUMPTION OF MAZOUT BY THE KILN IN 1990?

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FUTURE YEAR ENERGY CONSUMPTION

- FUEL SELECTED

$$\left(\begin{array}{c}\text{FUTURE}\\ \text{YEAR}\\ \text{FUEL SPECIFIC}\\ \text{CONSUMPTION}\end{array}\right) = \frac{\left(\begin{array}{c}\text{FUTURE YEAR}\\ \text{USEFUL ENERGY}\end{array}\right)}{\left(\begin{array}{c}\text{FUTURE YEAR}\\ \text{FUEL SPECIFIC}\\ \text{DEVICE}\\ \text{EFFICIENCY}\end{array}\right)}$$

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...CONVENTIONAL ENERGY CONSERVATION...

FUTURE YEAR DEVICE EFFICIENCY...

- FUEL SPECIFIC
- REFLECTS TECHNOLOGY FIX
  - NEW DEVICE, $\eta_1$
  - NEW DEVICE + MODERATE CONSERVATION, $\eta_2$
  - NEW DEVICE + ACCELERATED CONSERVATION, $\eta_3$

$$\eta_3 > \eta_2 > \eta_1 > \eta_{\text{base year}}$$

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## Comparison of Base-Year Efficiencies of Industrial-Sector End-Use Devices with Moderate and Enhanced Conservation

| Category of Useful Energy Demand | End-Use Device[a] | Base-Year Efficiency[b] ($\eta_B$) | Moderate Conservation Efficiency[b,c] ($\eta_M$) | Technical Change Limit[d] ($\eta_M/\eta_B$) | Enhanced Conservation Efficiency[b,c] ($\eta_E$) | Technical Change Limit[d] ($\eta_E/\eta_B$) | Improvement of $\eta_E$ over $\eta_M$ (%) |
|---|---|---|---|---|---|---|---|
| Direct heat - any fuel | Distillate oil furnace | 0.60 | 0.76 | 1.27 | 0.81 | 1.35 | 6.5 |
| | Residual oil furnace | 0.60 | 0.66 | 1.10 | 0.72 | 1.20 | 9.1 |
| | Coal furnace | 0.60 | 0.72 | 1.20 | 0.78 | 1.30 | 8.3 |
| | Natural gas furnace | 0.70 | 0.81 | 1.15 | 0.88 | 1.25 | 8.6 |
| Direct heat-clean fuel | LPG furnace | 0.70 | 0.81 | 1.15 | 0.84 | 1.20 | 3.7 |
| | Natural Gas furnace | 0.70 | 0.82 | 1.17 | 0.85 | 1.22 | 3.7 |
| | Electric furnace | 0.80 | 0.88 | 1.10 | 0.92 | 1.15 | 4.6 |
| Indirect heat | Distillate oil boiler | 0.70 | 0.84 | 1.20 | 0.91 | 1.30 | 8.3 |
| | Residual oil boiler | 0.69 | 0.79 | 1.15 | 0.85 | 1.23 | 5.1 |
| | Coal boiler | 0.60 | 0.72 | 1.20 | 0.78 | 1.30 | 8.3 |
| | Natural gas boiler | 0.80 | 0.88 | 1.10 | 0.94 | 1.17 | 6.8 |
| | Solar with gas backup[e] | 0.84 | 0.84 | 1.00 | 0.84 | 1.00 | 0 |
| Electrochemical and lighting | Electric device[f] | 0.69 | 0.72 | 1.05 | 0.76 | 1.10 | 5.6 |
| Feedstocks | Distillate | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0 |
| | LPG | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0 |
| | Natural Gas | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0 |

[a]Device efficiency data have been aggregated into generic categories from a disaggregated data set. The disaggregated data set is by type of device (such as, cement kiln, metal-melting furnace) and subsector (for example, food, cement).

[b]$\eta$ is the efficiency of the device and is the ratio of energy out (useful energy) to energy in (energy consumed).

[c]Efficiencies listed are the maximum obtainable for the conservation strategy. These efficiencies are applicable to new and replacement capacity of the device over the growth period.

[d]The ratio of the efficiency with conservation to the base-year efficiency; this is the maximum improvement achievable under the conservation assumption.

[e]The efficiency of the solar device with backup is a combined efficiency of both devices based on the shares of solar and backup usage.

[f]Including electric arc furnaces and electromechanical drive systems. Electromechanical drive (such as electric motors with mechanical coupling) dominates the demand-category energy consumption.

## FUTURE YEAR FUEL SWITCHING

SELECTION OF FUTURE YEAR FUEL TYPE.....

- RESTRICTED BY USEFUL ENERGY LABEL
- SELECTION BASIS...
  - FUEL AVAILABILITY
  - COMPARISON OF PROJECTED FUEL COSTS ($)
  - COMPARISON OF FUEL-SPECIFIC DEVICE CAPITAL AND OPERATING COSTS ($)

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## AGRICULTURE ENERGY DEMAND

- CROPS
- LIVESTOCK
- FORESTRY
- FISHING

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## AGRICULTURE ENERGY DEMAND

CROPS

- CEREALS
- OLEAGINOUS
- INDUSTRIAL
- LEGUMES & VEGETABLES
- FRUITS

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## AGRICULTURE ENERGY DEMAND

LIVESTOCK

- CATTLE
- SHEEP
- SWINE
- POULTRY

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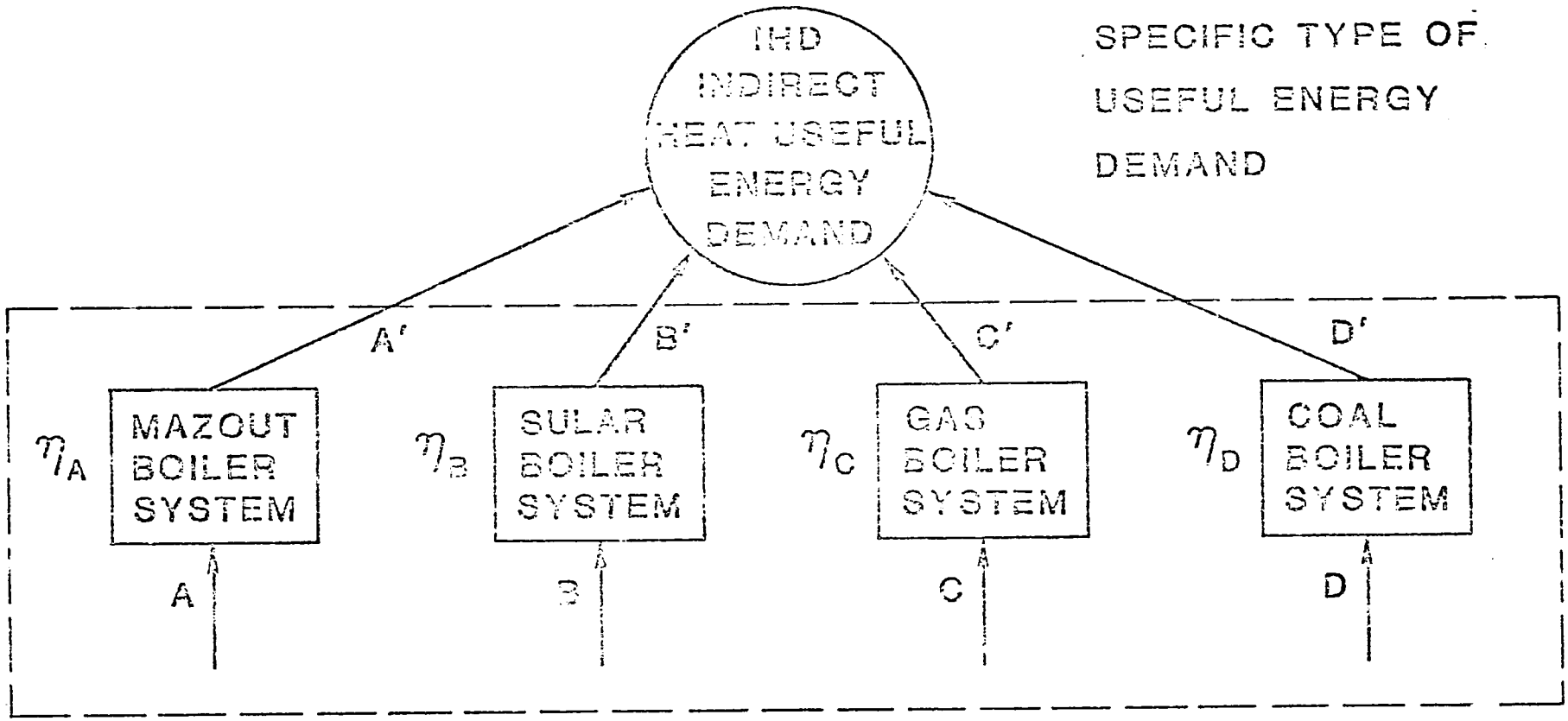
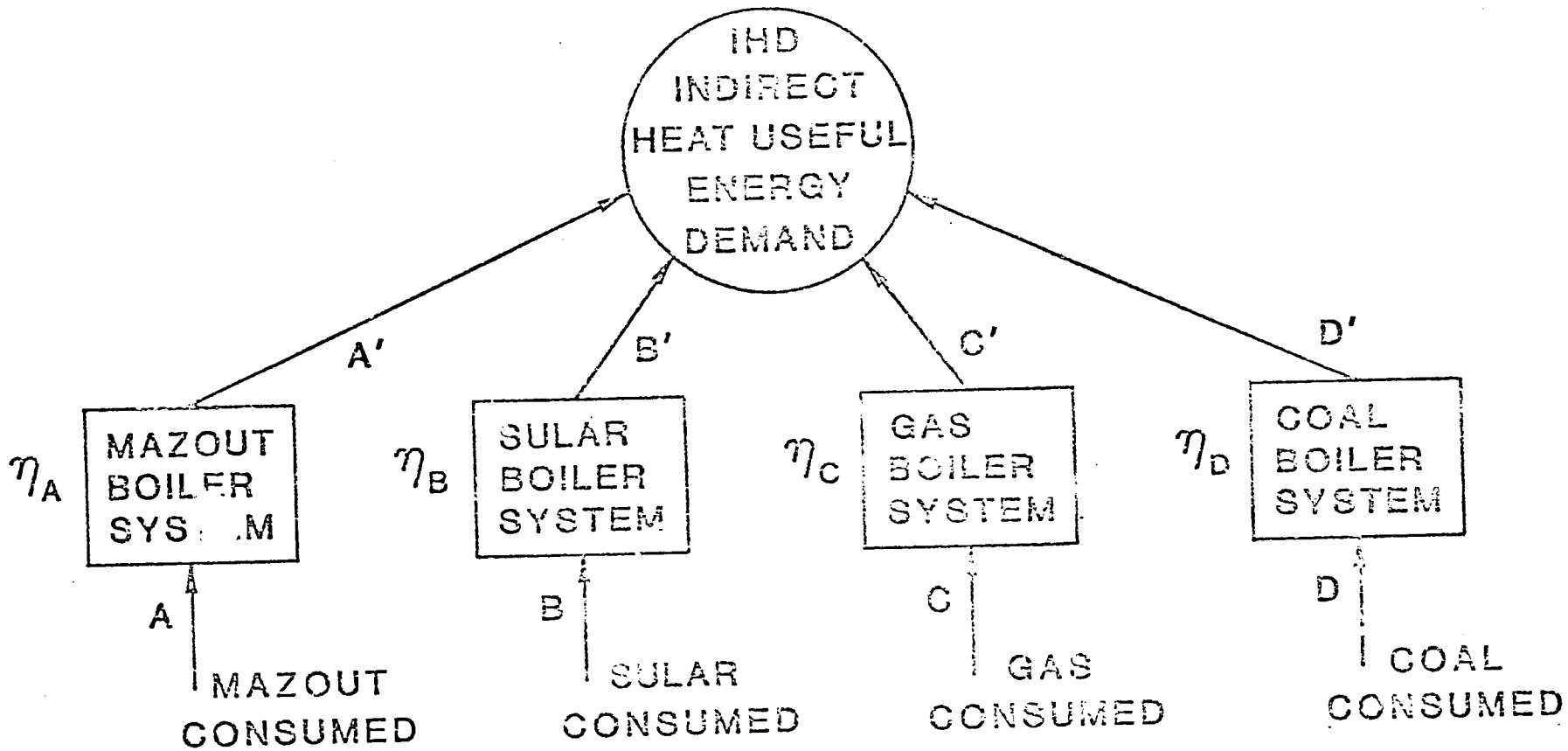
# DIFFERENT FUELS TO MEET ENERGY DEMAND




SPECIFIC TYPE OF USEFUL ENERGY DEMAND

FUEL SPECIFIC SYSTEMS THAT COULD ACCOMODATE THE USEFUL ENERGY DEMAND

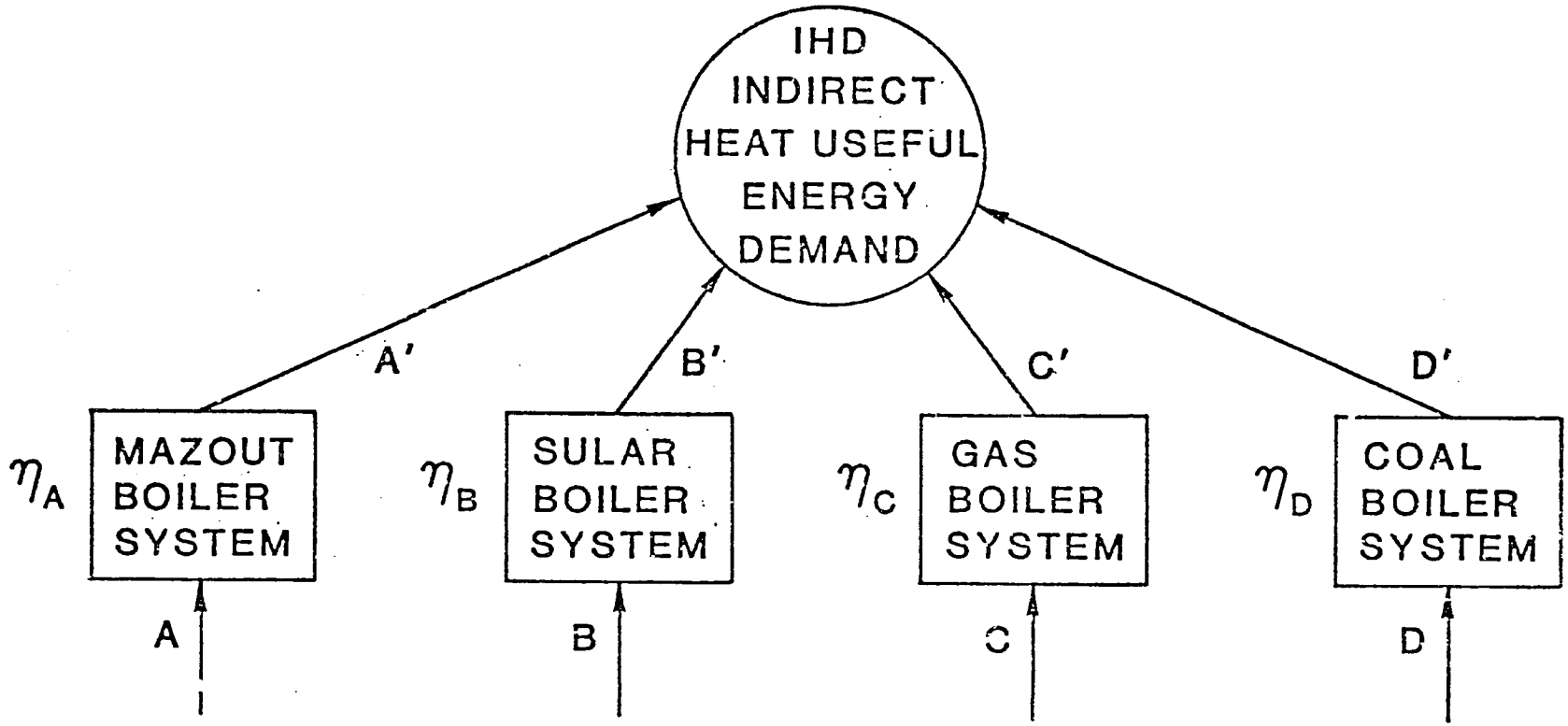
# DIFFERENT FUELS TO MEET ENERGY DEMAND




$$\text{IHD} = \begin{array}{l}\text{INDIRECT}\\ \text{HEAT}\\ \text{USEFUL}\\ \text{ENERGY}\\ \text{DEMAND}\end{array} = \sum \begin{array}{l}\text{USEFUL ENERGY FROM}\\ \text{ALL BOILERS}\end{array} = A + B + C + D$$

$$= \sum \eta_A A' + \eta_B B' + \eta_C C' + \eta_D D'$$

# COMPUTATION OF ENERGY DEMAND FROM DIFFERENT FUELS




- IF $A = 50 \times 10^6$ BTU/YR, $B = 40 \times 10^6$ BTU/YR, $C = 15 \times 10^6$ BTU/YR, $D = 5 \times 10^6$ BTU/YR, $\eta_A = 50\%$, $\eta_B = 70\%$, $\eta_C = 80\%$, $\eta_D = 75\%$
  WHAT IS THE TOTAL INDIRECT HEAT USEFUL ENERGY DEMAND (IHD)?

- WHAT IF C IS INCREASED BY 100% AND D IS INCREASED BY 50%
  WHAT HAPPENS TO A & B?

- HOW DO THE UNITS OF A,A', B,B', C,C', D,D', AND D,D' DIFFER FROM IHD?

# DIFFERENT FUELS TO MEET ENERGY DEMAND

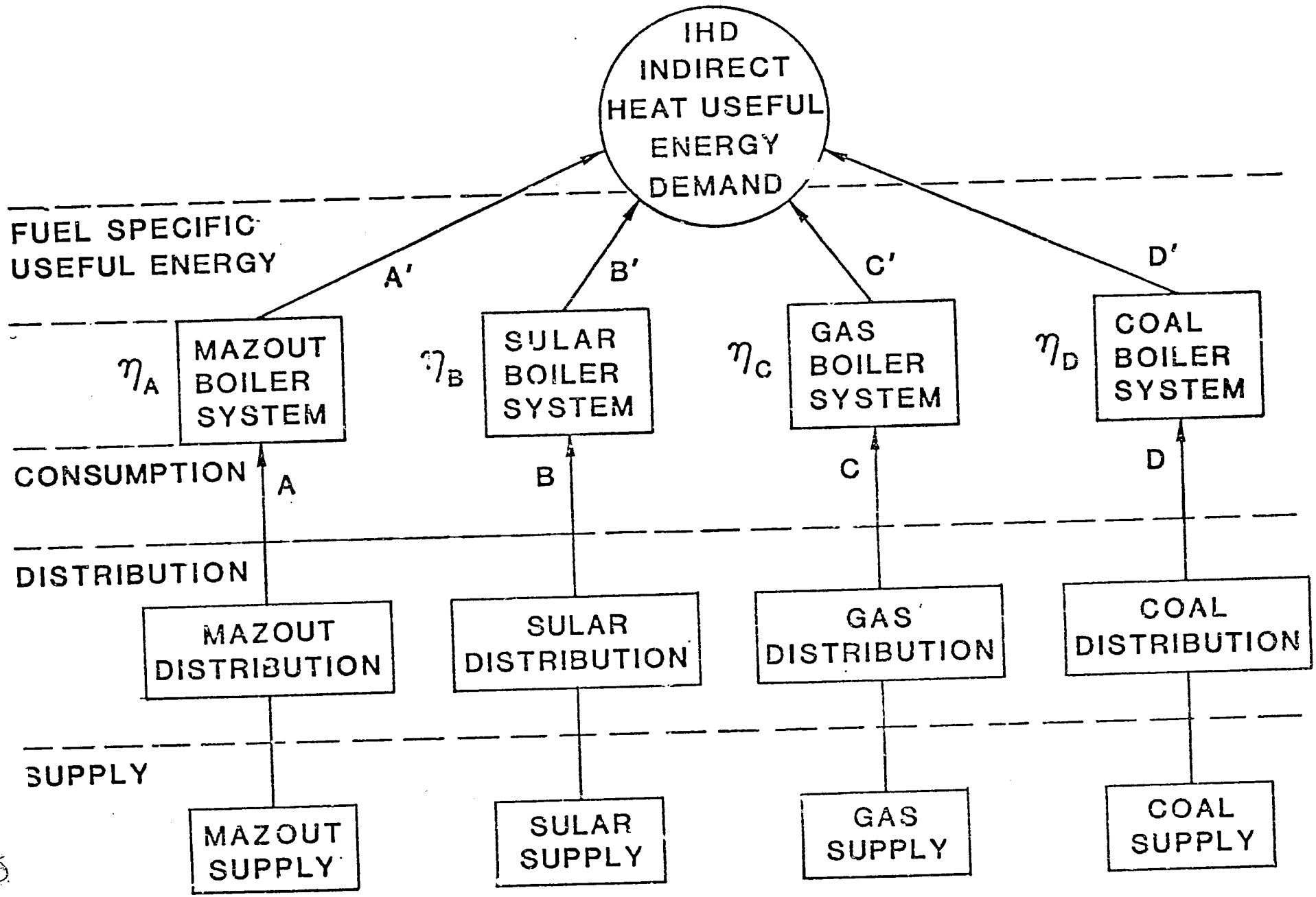


Table D-3 Base Year (1978) Industrial Energy Demand Data Food Industry ($10^3$ tep)[a]

| End-Use Device Energy Demand | Fuels and Other Energy Items | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Naphtha | Kerosene | Gas Oil | Diesel Fuel | Fuel Oil | Lubricants | Natural Gas | Biomass | Hydro-power | Purchased Electricity[b] | Auto-Generated Electricity[b] | Total Electric[c] | Total Energy[f] |
| **INDIRECT HEAT** | | | | | | | | | | | | | |
| Consumption | 84.0 | 29.6 | 183.6 | 22.0 | 708.5 | | | 379.0 | | | | | 1406.7 |
| Efficiency[d] | 0.7 | 0.7 | 0.7 | 0.7 | 0.7 | | | 0.6 | | | | | 0.6 |
| Useful Energy[e] | 58.8 | 20.7 | 20.7 | 128.5 | 495.9 | | | 227.4 | | | | | 946.7 |
| **DIRECT HEAT - ANY FUEL** | | | | | | | | | | | | | |
| Consumption | | | 26.0 | | 191.8 | | | | | | | | 217.8 |
| Efficiency | | | 0.6 | | 0.6 | | | | | | | | 0.6 |
| Useful Energy | | | 15.6 | | 115.1 | | | | | | | | 130.7 |
| **DIRECT HEAT - CLEAN FUEL** | | | | | | | | | | | | | |
| Consumption | | | | | | | 46.0 | | | | | | 46.0 |
| Efficiency | | | | | | | 0.7 | | | | | | 0.7 |
| Useful Energy | | | | | | | 32.2 | | | | | | 32.2 |
| **MOTIVE POWER** | | | | | | | | | | | | | |
| Consumption | | | | | | 17.79 | | | | 72.59 | (28.43)[f] | (101.0) | 90.38 |
| Efficiency | | | | | | 1.0 | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| Useful Energy | | | | | | 17.79 | | | | 50.81 | (19.9) | (70.7) | 111.6 |
| **REFRIGERATION** | | | | | | | | | | | | | |
| Consumption | | | | | | | | | | 74.60 | (29.21) | (103.8) | 74.60 |
| Efficiency | | | | | | | | | | 0.7 | 0.7 | 0.7 | 0.7 |
| Useful Energy | | | | | | | | | | 52.22 | (20.45) | (72.66) | 52.22 |
| **LIGHTING** | | | | | | | | | | | | | |
| Consumption | | | | | | | | | | 30.81 | (12.06) | (42.90) | 30.81 |
| Efficiency | | | | | | | | | | 0.2 | 0.2 | 0.2 | 0.2 |
| Useful Energy | | | | | | | | | | 6.16 | (2.41) | (8.58) | 6.16 |
| **AUTO-GENERATED ELECTRIC FUELS** | | | | | | | | | | | | | |
| Consumption | | | 74.0 | 22.0 | 36.9 | | 86.2 | 21.0 | (8) | | | | 240. |
| **TOTALS** | | | | | | | | | | | | | |
| Consumption | 84.0 | 29.6 | 283.6 | 44.0 | 937.2 | 17.79 | 132.2 | 400.0 | (8) | 178.0 | (69.7) | (247.7) | 2106.4 |
| Useful Energy | 58.8 | 20.7 | 144.1 | 15.4 | 611.0 | 17.79 | 32.2 | 227.4 | (3) | 109.19 | (42.76) | (151.94) | 1236.6 |

[a] 1 tep = $1.05 \times 10^7$ KCAL = $4.393 \times 10^{10}$ Joules.

[b] N is Device Efficiency = Useful/Consumption

[c] Useful Energy = Energy Consumption x End Use Device Efficiency.

[d] Source Electric Demand Consumption has been adjusted so that distribution by end use device is the same for purchased electricity and auto-generated electricity.

[e] Total energy includes fuels used to produce auto-generated electricity and excludes the auto-generated electricity produced to avoid double counting.

[f] Numbers in parentheses not included in totals.

# REGRESSION ANALYSIS WITH THE STATISTICAL ANALYSIS SYSTEM (SAS)

by
Karen A. Guziel
Energy & Environmental System Division
Argonne National Laboratory
May 28, 1985

# ARGONNE HAS 3 LEVELS OF COMPUTING CAPABILITY

- MAINFRAME - IBM 3033
- MINI - VAX 750
- MICRO - IBM PC

## SAS IS A TOOL FOR REGRESSION ANALYSIS (STATISTICAL ANALYSIS SYSTEM)

- AVAILABLE FOR ALL LEVELS OF COMPUTERS
- SUPPORTED BY THE SAS INSTITUE WHICH IS LOCATED IN NORTH CAROLINA, USA
- WORLDWIDE DISTRIBUTION AND SUPPORT

SAS DISTRIBUTOR FOR EGYPT

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Fax (966) 3-894-6560

Contact:
Mr. Tanweer Abbas (speaks Arabic)
Mr. Michael Brawn (speaks English)

# SAS IS A MULTIPURPOSE DATA ANALYSIS TOOL

- DATA STORAGE AND RETRIEVAL
- DATA MODIFICATION AND PROGRAMMING
- REPORT WRITING
- STATISTICAL ANALYSIS
- FILE HANDLING

# SAS HAS MANY EXTENSIONS WHICH INCREASE ITS CAPABILITY

- SAS/GRAPH GRAPHICS
- SAS/ETS TIME SERIES ANALYSIS AND FORECSTING
- SAS/OR OPERATIONS RESEARCH

## REGRESSION ANALYSIS / METHOD OF LEAST SQUARES

Given a set of x,y points find the line that passes nearest all the points and whose sum of distances from the actual point to the point of the line is minimized.

$$Y=b_0 + b_1 X$$

# LEAST SQUARE PARAMETER ESTIMATES

$$b_1 = \frac{\sum (X_i - \overline{X})(Y_i - \overline{Y})}{\sum (X_i - \overline{X})^2}$$

$$b_0 = \overline{Y} - b_1 \overline{X}$$

*Example 9.1:* Plot a scatter diagram and find the least squares line for the following data:

| | | | | | |
|---|---|---|---|---|---|
| $x_i$: | 1 | 2 | 3 | 4 | 5 |
| $y_i$: | 3 | 6 | 7 | 8 | 11 |

The scatter diagram for this data is shown in Figure 9.8. In order to find $b_0$ and $b_1$ it is helpful to arrange the numbers in a table such as we have done in Table 9.2. From this table, it is easy to find the sums necessary to calculate $b_0$ and $b_1$. From Equation (9.4), we find

$$b_1 = \sum (x_i - \bar{x})(y_i - \bar{y}) / \sum (x_i - \bar{x})^2 = 18/10 = 1.8$$

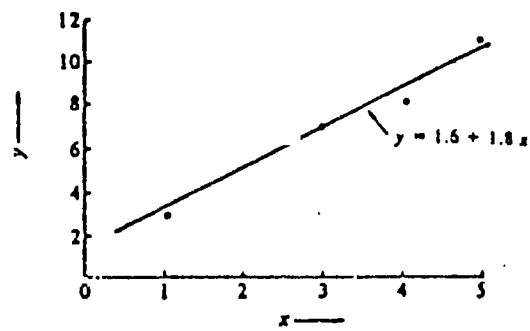



FIGURE 9.8
*Scatter Diagram and Least Squares Line for Example 9.1*

TABLE 9.2
*Sums Needed for Example 9.1*

| | $x_i$ | $y_i$ | $(x_i - \bar{x})$ | $(y_i - \bar{y})$ | $(x_i - \bar{x})\cdot(y_i - \bar{y})$ | $(x_i - \bar{x})^2$ |
|---|---|---|---|---|---|---|
| | 1 | 3 | −2 | −4 | 8 | 4 |
| | 2 | 6 | −1 | −1 | 1 | 1 |
| | 3 | 7 | 0 | 0 | 0 | 0 |
| | 4 | 8 | 1 | 1 | 1 | 1 |
| | 5 | 11 | 2 | 4 | 8 | 4 |
| $\Sigma$: | 15 | 35 | 0 | 0 | 18 | 10 |

and from Equation (9.5), we find

$$b_0 = \bar{y} - b_1\bar{x} = 7 - (1.8)(3) = 1.6$$

The least squares line is

$$b_0 + b_1 x = 1.6 + 1.8x$$

In this example, $b_0 = 1.6$ is a point estimate of $\beta_0$ and $b_1 = 1.8$ is a point estimate of $\beta_1$. The line $1.6 + 1.8x$ is an estimate of the true regression line $\beta_0 + \beta_1 x$. This estimated regression line is shown in Figure 9.8.

# REGRESSION ANALYSIS CAN BE USED AS A FORECASTING TOOL

- LOAD GROWTH
- DEMAND BY SECTOR
- ENERGY REQUIRMENTS

# A GOOD MODEL

- SIMPLE
- ACCURATE
- MEANINGFUL

## CONSIDERATIONS WHEN GATHERING DATA FOR ANAYSIS

- TIME
- MONEY
- COMPLETENESS
- ACCURACY & RELIABILITY
- DISAGGREGATE
- MAJOR SOCIAL/ECONOMIC CHANGES

PROCEDURE REG IS USED TO GENERATE THE LEAST SQUARES LINE FOR A LINEAR MODEL
CAPABILITIES OF PROC REG INCLUDE:

- multilple MODEL statements
- print predicted values, residuals, studentized residuals and confidence limits
- print special influence statistics
- produce partial regression leverage plots
- estimate parameters subject to linear restrictions
- test linear hypotheses

# OUTPUT CHECKLIST

- REVIEW PARAMETER ESTIMATES AND THEIR ASSOCIATED ALGEBRAIC SIGNS ---are they intuitive---
- $R^2$ - RELATES THE % OF VARIATION IN THE DEPENDENT VARIABLE EXPLAINABLE BY THE INDEPENDENT VARIABLE --- NEAR 1 IMPLIES STRONG RELATIONSHIP BETWEEN X & Y
- CORRELATION ESTIMATE - CORRELATION AMONG INDEPDENT VARIABLES

## OUTPUT CHECKING (cont.)

- DURBIN-WATSON TEST FOR RESIDUAL INDEPENDENCE
  D=2 - independent
  D=0 - positive auto correlation
  D=4 - negative auto correlation

- EFFECTS OF POSITIVE AUTO CORRELATION
  1) coefficient estimates not efficient
  2) sub-optimal forecast
  3) variance underestimated
  4) model may be misspecified

- COOK'S D STATISTIC
  IF > 1 OBSERVATION IS INFLUENTIAL

- EIGENVALUES
  IF MAX/MIN > 10 THERE IS MULTI COLLINEARITY

- VIF - VARIANCE INFLATION FACTOR
  inverse of corrrlation matrix
  IF > 10 there is a problem with the model

## OUTPUT CHECKING (cont.)
## SIGNS OF MULTI-COLLINEARITY

- F-TEST AND $R^2$ SIGNIFICANT BUT NONE OR ONLY 1 COEFFICIENT SIGNIFICANT
- ALGRBRAIC SIGNS NOT AS EXPECTED
- LARGE CHANGE IN COEFFICIENT WHEN A VARIABLE IS ADDED OR DELETED
- LARGE CHANGE IN COEFFICIENT WHEN A DATA POINT IS ADDED OR DELETED
- LARGE STANDARD ERROR OF COEFFICIENT
- CORRELATION AMONG INDEPENDENT VARIABLES

# OUTPUT CHECKLIST (cont.)

## REVIEW PLOT OF RESIDUALS

- LINEAR RELATIONSHIP
- RANDOM
- CONSTANT VARIANCE
- INDEPENDENT
- OUTLIERS
- SEQUENCE

A survey of the clerical employees of a large financial organization includes questions related to employee satisfaction with their supervisor. There was a question regarding the overall performance of a supervisor as well as questions that related to specific activities involving interaction between the supervisor and the employee. An exploratory study was undertaken to try to explain the relationship between specific supervisor characteristics and overall satisfaction with supervisors as perceived by the employees. Initially, six questionnaire items were chosen as possible explanatory variables. A description of the variables is as follows.

| Variable | Description |
|---|---|
| $Y$ | Overall rating of supervisor |
| $X_1$ CMPLNT | Handles employee complaints |
| $X_2$ PRIV | Does not allow special privileges |
| $X_3$ OPPOR | Opportunity to learn new things |
| $X_4$ RAISES | Raises based on performance |
| $X_5$ CRIT | Too critical of poor performance |
| $X_6$ ADVANC | Rate of advancing to better job |

| OBS | RATING | CMPLNT | PREV | OPPOR | RAISES | CRIT | ADVANC | COUNT |
|---|---|---|---|---|---|---|---|---|
| 1 | 43 | 51 | 30 | 39 | 61 | 92 | 45 | 1 |
| 2 | 63 | 64 | 51 | 54 | 63 | 73 | 47 | 2 |
| 3 | 71 | 70 | 68 | 69 | 76 | 86 | 48 | 3 |
| 4 | 61 | 63 | 45 | 47 | 54 | 84 | 35 | 4 |
| 5 | 81 | 78 | 56 | 66 | 71 | 83 | 47 | 5 |
| 6 | 43 | 55 | 49 | 44 | 54 | 69 | 34 | 6 |
| 7 | 58 | 67 | 42 | 56 | 66 | 63 | 35 | 7 |
| 8 | 71 | 75 | 50 | 55 | 78 | 66 | 41 | 8 |
| 9 | 72 | 82 | 72 | 67 | 71 | 83 | 31 | 9 |
| 10 | 67 | 61 | 45 | 47 | 62 | 80 | 41 | 10 |
| 11 | 64 | 53 | 53 | 53 | 58 | 67 | 34 | 11 |
| 12 | 67 | 60 | 47 | 39 | 59 | 74 | 41 | 12 |
| 13 | 69 | 62 | 57 | 42 | 55 | 63 | 25 | 13 |
| 14 | 68 | 83 | 83 | 45 | 59 | 77 | 35 | 14 |
| 15 | 77 | 77 | 54 | 72 | 79 | 77 | 46 | 15 |
| 16 | 81 | 90 | 50 | 72 | 60 | 54 | 35 | 16 |
| 17 | 74 | 85 | 64 | 69 | 70 | 79 | 63 | 17 |
| 18 | 65 | 60 | 65 | 75 | 55 | 80 | 60 | 18 |
| 19 | 65 | 70 | 46 | 57 | 75 | 85 | 46 | 19 |
| 20 | 50 | 58 | 63 | 54 | 64 | 78 | 52 | 20 |
| 21 | 50 | 40 | 33 | 34 | 43 | 64 | 33 | 21 |
| 22 | 64 | 61 | 52 | 62 | 66 | 80 | 41 | 22 |
| 23 | 53 | 66 | 52 | 50 | 63 | 80 | 37 | 23 |
| 24 | 40 | 37 | 42 | 53 | 50 | 57 | 49 | 24 |
| 25 | 63 | 54 | 42 | 48 | 66 | 75 | 33 | 25 |
| 26 | 66 | 77 | 66 | 63 | 85 | 76 | 72 | 26 |
| 27 | 78 | 75 | 58 | 74 | 80 | 78 | 49 | 27 |
| 28 | 48 | 57 | 44 | 45 | 51 | 83 | 33 | 28 |
| 29 | 85 | 85 | 71 | 71 | 77 | 74 | 55 | 29 |
| 30 | 82 | 82 | 39 | 59 | 64 | 78 | 39 | 30 |

MODEL CROSSPRODUCTS X'X X'Y Y'Y

| X'X | INTERCEP | CMPLNT | PRIV | OPPOR | RAISES | CRIT | ADVANC | RATING |
|---|---|---|---|---|---|---|---|---|
| INTERCEP | 30 | 1998 | 1594 | 1691 | 1939 | 2243 | 1288 | 1939 |
| CMPLNT | 1998 | 133208 | 105798 | 115325 | 131824 | 150101 | 86673 | 133017 |
| PRIV | 1594 | 105798 | 89036 | 91903 | 104669 | 119695 | 69039 | 104866 |
| OPPOR | 1691 | 115325 | 91903 | 99311 | 111561 | 126221 | 74462 | 111879 |
| RAISES | 1939 | 131824 | 104669 | 111561 | 128459 | 146097 | 85029 | 127490 |
| CRIT | 2243 | 150101 | 119695 | 126221 | 146097 | 170541 | 97136 | 145519 |
| ADVANC | 1288 | 86673 | 69039 | 74462 | 85029 | 97136 | 59368 | 83811 |
| RATING | 1939 | 133017 | 104866 | 111879 | 127490 | 145519 | 83811 | 129621 |

SEQUENTIAL PARAMETER ESTIMATES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| INTERCEP | 64.6333 | | | | | | |
| CMPLNT | 14.3763 | 0.75461 | | | | | |
| PRIV | 15.3276 | 0.780343 | -0.05016 | | | | |
| OPPOR | 11.2583 | 0.682416 | -.103284 | 0.237976 | | | |
| RAISES | 11.8335 | 0.691149 | -.102886 | 0.246331 | -.025512 | | |
| CRIT | 11.0111 | 0.692053 | -.103562 | 0.249061 | -.033461 | .0154833 | |
| ADVANC | 10.7871 | 0.613188 | -0.07305 | 0.320332 | .0817321 | .0333314 | -.217057 |

X'X INVERSE, B, SSE

| INVERSE | INTERCEP | CMPLNT | PRIV | OPPOR | RAISES | CRIT | ADVANC | RATING |
|---|---|---|---|---|---|---|---|---|
| INTERCEP | 2.688555 | -0.0025433 | -0.00363362 | -0.00615359 | -0.00432962 | -0.0226605 | 0.0006562191 | 10.78708 |
| CMPLNT | -0.0025433 | 0.0005187622 | -0.000163635 | -0.000163834 | -0.000371772 | 4.677588E-07 | 0.0002309832 | 0.6131876 |
| PRIV | -0.00363362 | -0.000163635 | 0.0003687444 | -.0000625115 | .000046716729 | -.0000091563 | -.0000393645 | -0.0730501 |
| OPPOR | -0.00615359 | -0.000163834 | -.0000625115 | 0.0005624761 | -0.000153932 | 0.0000970261 | -0.000208741 | 0.3203321 |
| RAISES | -0.00432962 | -0.000371772 | .000046716729 | -0.000153932 | 0.0009317000 | -0.000182773 | -0.000337381 | 0.08173213 |
| CRIT | -0.0226605 | 4.677588E-07 | -.0000091563 | 0.0000970261 | -0.000182773 | 0.0004325292 | -.0000670503 | 0.03833145 |
| ADVANC | 0.0006562191 | 0.0002309832 | -.0000393645 | -0.000208741 | -0.000337381 | -.0000670503 | 0.0006357249 | -0.217057 |
| RATING | 10.78708 | 0.6131876 | -0.0730501 | 0.3203321 | 0.08173213 | 0.03833145 | -0.217057 | 1149 |

DEP VARIABLE: RATING

| SOURCE | DF | SUM OF SQUARES | MEAN SQUARE | F VALUE | PROB>F |
|---|---|---|---|---|---|
| MODEL | 6 | 3147.966 | 524.661 | 10.502 | 0.0001 |
| ERROR | 23 | 1149.000 | 49.956536 | | |
| C TOTAL | 29 | 4296.967 | | | |

| | | | |
|---|---|---|---|
| ROOT MSE | 7.067994 | R-SQUARE | 0.7326 |
| DEP MEAN | 64.633333 | ADJ R-SQ | 0.6623 |
| C.V. | 10.93552 | | |

| VARIABLE | DF | PARAMETER ESTIMATE | STANDARD ERROR | T FOR H0: PARAMETER=0 | PROB > \|T\| | TYPE I SS | TYPE II SS | STANDARDIZED ESTIMATE | TOLERANCE | VARIANCE INFLATION |
|---|---|---|---|---|---|---|---|---|---|---|
| INTERCEP | 1 | 10.787076 | 11.589257 | 0.931 | 0.3616 | 125324 | 43.280136 | 0.000000 | . | 0.000000 |
| CMPLNT | 1 | 0.613183 | 0.160933 | 3.809 | 0.0009 | 2927.504 | 724.800 | 0.670725 | 0.374945 | 2.667069 |
| PRIV | 1 | -0.073050 | 0.135725 | -0.533 | 0.5956 | 7.513562 | 14.471606 | -0.073427 | 0.624652 | 1.600391 |
| OPPOR | 1 | 0.320332 | 0.168520 | 1.901 | 0.0609 | 137.247 | 180.505 | 0.305370 | 0.440326 | 2.271043 |
| RAISES | 1 | 0.087732 | 0.221473 | 0.369 | 0.7155 | 0.942175 | 6.003276 | 0.069312 | 0.326862 | 3.078226 |
| CRIT | 1 | 0.038381 | 0.146995 | 0.261 | 0.7963 | 0.563037 | 3.405364 | 0.031200 | 0.814260 | 1.228109 |
| | 1 | -0.217057 | 0.178209 | -1.218 | 0.2356 | 74.110044 | 74.110044 | -0.183464 | 0.512402 | 1.951591 |

COVARIANCE OF ESTIMATES

| COVB | INTERCEP | CMPLNT | PRIV | OPPOR | RAISES | CRIT | ADVANC |
|---|---|---|---|---|---|---|---|
| INTERCEP | 134.3109 | -0.127054 | -0.181523 | -0.307412 | -0.216293 | -1.13204 | 0.03278243 |
| CMPLNT | -0.127054 | 0.02591556 | -0.00817463 | -0.00318457 | -0.0105725 | .00002336757 | 0.01153912 |
| PRIV | -0.181523 | -0.00817463 | 0.01842119 | -0.00312886 | 0.002306358 | -0.000457418 | -0.00446434 |
| OPPOR | -0.307412 | -0.00318457 | -0.00312886 | 0.0283921 | -0.00768989 | 0.004847088 | -0.010428 |
| RAISES | -0.216293 | -0.0105725 | 0.002306358 | -0.00768989 | 0.04905236 | -0.00913073 | -0.0163544 |
| CRIT | -1.13204 | .00002336757 | -0.000457418 | 0.004847088 | -0.00913073 | 0.02160766 | -0.0033496 |
| ADVANC | 0.03278243 | 0.01153912 | -0.00446434 | -0.010428 | -0.0163544 | -0.0033496 | 0.03175862 |

CORRELATION OF ESTIMATES

| CORRB | INTERCEP | CMPLNT | PRIV | OPPOR | RAISES | CRIT | ADVANC |
|---|---|---|---|---|---|---|---|
| INTERCEP | 1.0000 | -0.0681 | -0.1154 | -0.1574 | -0.0843 | -0.6645 | 0.0159 |
| CMPLNT | -0.0681 | 1.0000 | -0.3741 | -0.3017 | -0.5209 | 0.0010 | 0.4022 |
| PRIV | -0.1154 | -0.3741 | 1.0000 | -0.1335 | 0.0767 | -0.0229 | -0.1846 |
| OPPOR | -0.1574 | -0.3017 | -0.1335 | 1.0000 | -0.2060 | 0.1957 | -0.3472 |
| RAISES | -0.0843 | -0.5209 | 0.0767 | -0.2060 | 1.0000 | -0.2005 | -0.4270 |
| CRIT | -0.6645 | 0.0010 | -0.0229 | 0.1957 | -0.2005 | 1.0000 | -0.1279 |
| ADVANC | 0.0159 | 0.4022 | -0.1846 | -0.3472 | -0.4270 | -0.1279 | 1.0000 |

COLLINEARITY DIAGNOSTICS VARIANCE PROPORTIONS

| NUMBER | EIGENVALUE | CONDITION INDEX | PORTION INTERCEP | PORTION CHFLNT | PORTION PRIV | PORTION OPPOR | PORTION RAISES | PORTION CRIT | PORTION ADVANC |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.875 | 1.000 | 0.0003 | 0.0003 | 0.0006 | 0.0004 | 0.0002 | 0.0003 | 0.0006 |
| 2 | 0.039867 | 13.132 | 0.0028 | 0.0760 | 0.1973 | 0.0022 | 0.0095 | 0.0175 | 0.3059 |
| 3 | 0.035233 | 13.968 | 0.0796 | 0.0006 | 0.0644 | 0.0677 | 0.0001 | 0.1230 | 0.1759 |
| 4 | 0.023502 | 17.104 | 0.0033 | 0.0941 | 0.6577 | 0.1579 | 0.0220 | 0.0142 | 0.0324 |
| 5 | 0.012765 | 23.208 | 0.1414 | 0.2497 | 0.0064 | 0.6078 | 0.0774 | 0.0006 | 0.1233 |
| 6 | 0.007579 | 30.118 | 0.7523 | 0.0594 | 0.0224 | 0.1582 | 0.0160 | 0.6754 | 0.1168 |
| 7 | 0.005807 | 34.409 | 0.0203 | 0.4991 | 0.0512 | 0.0093 | 0.8337 | 0.1641 | 0.2418 |

| OBS | ACTUAL | PREDICT VALUE | STD ERR PREDICT | LOWER95% MEAN | UPPER95% MEAN | LOWER95% PREDICT | UPPER95% PREDICT | RESIDUAL | STD ERR RESIDUAL | STUDENT RESIDUAL | -2-1-0 1 2 | COOK'S D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 43.000 | 51.110 | 4.136 | 42.555 | 59.665 | 34.170 | 68.050 | -8.110 | 5.732 | -1.415 | \| **\| \| | 0.149 |
| 2 | 63.000 | 61.353 | 1.635 | 57.970 | 64.735 | 46.345 | 76.360 | 1.647 | 6.876 | 0.240 | \| \| \| | 0.000 |
| 3 | 71.000 | 69.939 | 3.137 | 63.450 | 76.429 | 53.943 | 85.936 | 1.061 | 6.334 | 0.167 | \| \| \| | 0.001 |
| 4 | 61.000 | 61.227 | 2.870 | 55.289 | 67.165 | 45.443 | 77.003 | -.226842 | 6.459 | -0.035 | \| \| \| | 0.000 |
| 5 | 81.000 | 74.454 | 2.141 | 70.024 | 78.883 | 59.176 | 89.731 | 6.546 | 6.736 | 0.972 | \| \|* \| | 0.014 |
| 6 | 43.000 | 53.942 | 3.924 | 45.824 | 62.060 | 37.213 | 70.665 | -10.942 | 5.878 | -1.861 | \| ***\| \| | 0.221 |
| 7 | 58.000 | 67.143 | 2.492 | 61.993 | 72.304 | 51.645 | 82.652 | -9.143 | 6.614 | -1.383 | \| **\| \| | 0.039 |
| 8 | 71.000 | 70.097 | 2.563 | 64.794 | 75.400 | 54.544 | 85.650 | 0.902993 | 6.587 | 0.137 | \| \| \| | 0.000 |
| 9 | 72.000 | 79.531 | 4.017 | 71.222 | 87.840 | 62.714 | 96.348 | -7.531 | 5.816 | -1.295 | \| **\| \| | 0.114 |
| 10 | 67.000 | 59.198 | 1.943 | 55.180 | 63.217 | 44.035 | 74.362 | 7.802 | 6.796 | 1.148 | \| \|** \| | 0.015 |
| 11 | 64.000 | 57.926 | 3.043 | 51.630 | 64.221 | 42.007 | 73.845 | 6.074 | 6.379 | 0.952 | \| \|* \| | 0.029 |
| 12 | 67.000 | 55.401 | 2.640 | 49.940 | 60.862 | 39.793 | 71.009 | 11.599 | 6.557 | 1.769 | \| \|*** \| | 0.072 |
| 13 | 69.000 | 59.582 | 3.353 | 52.645 | 66.518 | 43.399 | 75.765 | 9.418 | 6.222 | 1.514 | \| \|*** \| | 0.075 |
| 14 | 68.000 | 70.214 | 5.196 | 59.464 | 80.964 | 52.067 | 88.332 | -2.214 | 4.791 | -0.462 | \| \| \| | 0.036 |
| 15 | 77.000 | 76.549 | 2.837 | 70.681 | 82.417 | 60.795 | 92.304 | 0.450671 | 6.474 | 0.070 | \| \| \| | 0.000 |
| 16 | 81.000 | 84.548 | 5.185 | 73.821 | 95.275 | 66.414 | 102.682 | -3.548 | 4.803 | -0.739 | \| *\| \| | 0.091 |
| 17 | 74.000 | 76.150 | 3.316 | 69.291 | 83.009 | 60.000 | 92.300 | -2.150 | 6.242 | -0.344 | \| \| \| | 0.005 |
| 18 | 65.000 | 61.397 | 5.209 | 50.621 | 72.174 | 43.234 | 79.561 | 3.603 | 4.777 | 0.754 | \| \|* \| | 0.097 |
| 19 | 65.000 | 68.017 | 2.587 | 62.665 | 73.368 | 52.447 | 83.586 | -3.017 | 6.578 | -0.459 | \| \| \| | 0.005 |
| 20 | 50.000 | 55.620 | 3.120 | 49.165 | 62.075 | 39.633 | 71.603 | -5.620 | 6.342 | -0.886 | \| *\| \| | 0.027 |
| 21 | 50.000 | 42.603 | 3.431 | 35.506 | 49.700 | 26.351 | 58.876 | 7.397 | 6.179 | 1.197 | \| \|** \| | 0.063 |
| 22 | 64.000 | 63.819 | 2.364 | 58.923 | 68.710 | 46.402 | 79.236 | 0.180993 | 6.661 | 0.027 | \| \| \| | 0.000 |
| 23 | 53.000 | 63.664 | 1.827 | 59.835 | 67.443 | 48.582 | 78.766 | -10.664 | 6.833 | -1.562 | \| ***\| \| | 0.025 |
| 24 | 40.000 | 44.625 | 4.533 | 35.247 | 54.003 | 27.255 | 61.995 | -4.625 | 5.423 | -0.853 | \| *\| \| | 0.073 |
| 25 | 63.000 | 57.317 | 3.169 | 50.762 | 63.872 | 41.234 | 73.340 | 5.683 | 6.318 | 0.899 | \| \|* \| | 0.029 |
| 26 | 66.000 | 67.843 | 4.956 | 57.591 | 78.096 | 49.926 | 85.761 | -1.843 | 5.029 | -0.366 | \| \| \| | 0.018 |
| 27 | 78.000 | 75.140 | 2.921 | 69.098 | 81.183 | 59.320 | 90.961 | 2.860 | 6.436 | 0.444 | \| \| \| | 0.006 |
| 28 | 48.000 | 56.045 | 2.968 | 49.905 | 62.185 | 40.187 | 71.903 | -8.045 | 6.415 | -1.254 | \| **\| \| | 0.048 |
| 29 | 85.000 | 77.661 | 2.7[illegible] | 71.933 | 83.333 | 61.976 | 93.345 | 7.339 | 6.513 | 1.127 | \| \|** \| | 0.032 |
| 30 | 82.000 | 76.878 | 3.804 | 69.010 | 84.747 | 60.275 | 93.482 | 5.122 | 5.957 | 0.860 | \| \|* \| | 0.043 |

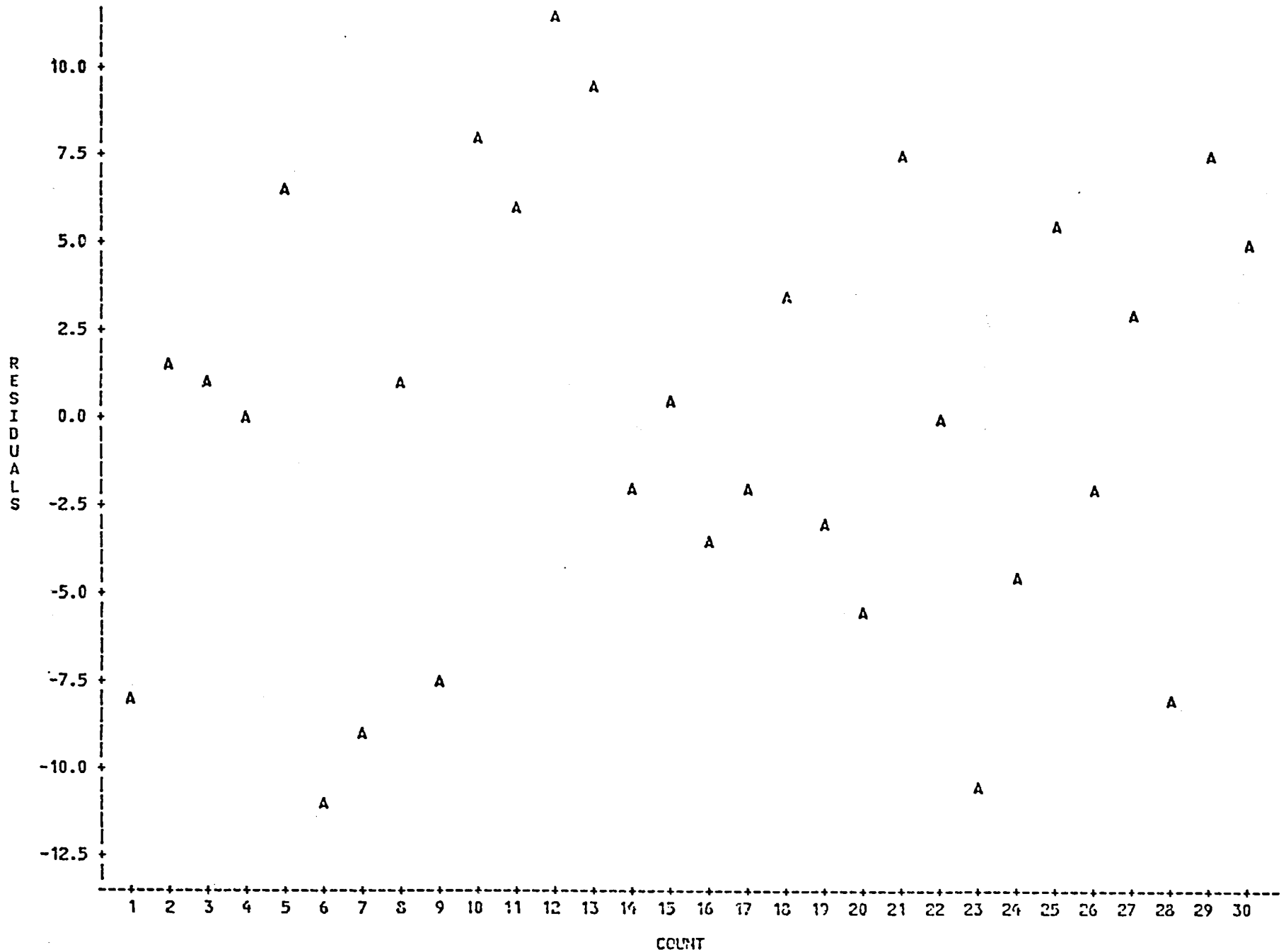
SUM OF RESIDUALS 4.12115E-13
SUM OF SQUARED RESIDUALS 1149

| OBS | RESIDUAL | RSTUDENT | HAT DIAG H | COV RATIO | DFFITS | DFBETAS INTERCEP | DFBETAS CHFLNT | DFBETAS PRIV | DFBETAS OPPOR | DFBETAS RAISES | DFBETAS CRIT | DFBETAS ADVANC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -8.1103 | -1.4484 | 0.3424 | 1.0972 | -1.0450 | 0.1193 | -0.0293 | 0.5024 | 0.3049 | 0.0006 | -0.5531 | -0.2460 |
| 2 | 1.64723 | 0.2346 | 0.0535 | 1.4172 | 0.0538 | 0.0165 | 0.0099 | -0.0030 | -0.0157 | -0.0109 | -0.0110 | 0.0319 |
| 3 | 1.06056 | 0.1639 | 0.1370 | 1.6354 | 0.0612 | -0.0434 | -0.0165 | 0.0321 | 0.0305 | 0.0235 | 0.0311 | -0.0330 |
| 4 | -.226842 | -0.0343 | 0.1649 | 1.6340 | -0.0153 | 0.0009 | -0.0052 | 0.0033 | 0.0001 | 0.0085 | -0.0102 | 0.0003 |

| OBS | RESIDUAL | RSTUDENT | HAT DIAG H | COV RATIO | DFFITS | DFBETAS INTERCEP | DFBETAS CMPLNT | DFBETAS FRIV | DFBETAS OPPOR | DFBETAS RAISES | DFBETAS CRIT | DFBETAS ADVANC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 6.5462 | 0.9706 | 0.0918 | 1.1207 | 0.3036 | -0.1719 | 0.1092 | -0.0325 | 0.1025 | -0.0720 | 0.1488 | 0.0102 |
| 6 | -10.9418 | -1.9753 | 0.3083 | 0.6293 | -1.3136 | -1.1239 | 0.1499 | -0.2091 | 0.3355 | -0.2507 | 1.1157 | 0.0087 |
| 7 | -9.[illegible]4841 | -1.4128 | 0.1243 | 0.8437 | -0.5323 | -0.2900 | 0.0169 | 0.2605 | -0.0767 | -0.2240 | 0.1872 | 0.2327 |
| 8 | 0.902993 | 0.1341 | 0.1315 | 1.5623 | 0.0522 | 0.0131 | 0.[illegible] | -0.0146 | -0.0195 | 0.0205 | -0.0328 | 0.0003 |
| 9 | -7.53099 | -1.3153 | 0.3229 | 1.1843 | -0.9034 | 0.3527 | [illegible] | -0.4210 | -0.3119 | -0.1164 | -0.3123 | 0.6742 |
| 10 | 7.20154 | 1.1564 | 0.0755 | 0.9769 | 0.3305 | 0.0193 | [illegible]462 | -0.0936 | -0.1302 | 0.0079 | 0.1178 | 0.0332 |
| 11 | 6.07423 | 0.9502 | 0.1354 | 1.2645 | 0.4533 | 0.1651 | -0.3120 | 0.1446 | 0.2339 | 0.0913 | -0.0706 | -0.2668 |
| 12 | 11.599 | 1.8615 | 0.1395 | 0.5698 | 0.7494 | 0.2690 | 0.1826 | -0.0134 | -0.6059 | 0.0967 | -0.0776 | 0.2683 |
| 13 | 9.41332 | 1.5602 | 0.2251 | 0.8450 | 0.8408 | 0.4496 | -0.0953 | 0.4000 | -0.2654 | 0.1608 | -0.3032 | -0.4056 |
| 14 | -2.21401 | -0.4541 | 0.5405 | 2.7831 | -0.4925 | 0.0320 | -0.1690 | -0.3703 | 0.2325 | 0.1332 | -0.0373 | -0.0053 |
| 15 | 0.450671 | 0.0681 | 0.1611 | 1.6247 | 0.0298 | -0.0092 | -0.0063 | -0.0077 | 0.0140 | 0.0153 | -0.0013 | -0.0118 |
| 16 | -3.54785 | -0.7312 | 0.5382 | 2.4903 | -0.7894 | -0.2461 | -0.4020 | 0.3007 | -0.2435 | 0.3319 | 0.3163 | -0.0414 |
| 17 | -2.15013 | -0.3378 | 0.2201 | 1.6380 | -0.1794 | 0.0643 | -0.0518 | 0.0192 | 0.0401 | 0.0210 | 0.0185 | -0.1354 |
| 18 | 3.60264 | 0.7469 | 0.5432 | 2.5079 | 0.8145 | -0.1163 | -0.0433 | 0.1393 | 0.4339 | -0.5657 | 0.2432 | 0.3183 |
| 19 | -3.01656 | -0.4506 | 0.1340 | 1.4780 | -0.1772 | 0.0673 | 0.0067 | 0.0786 | 0.0202 | -0.0263 | -0.0571 | 0.0181 |
| 20 | -5.62014 | -0.8819 | 0.1949 | 1.3294 | -0.4339 | 0.0373 | 0.1802 | -0.3157 | 0.0768 | 0.0097 | -0.0254 | -0.1146 |
| 21 | 7.38676 | 1.2089 | 0.2356 | 1.1334 | 0.6712 | 0.5422 | -0.0666 | -0.1214 | -0.1309 | -0.1553 | -0.1353 | 0.1113 |
| 22 | 0.180983 | 0.0266 | 0.1119 | 1.5366 | 0.0094 | -0.0019 | -0.0057 | 0.0085 | 0.0035 | 0.0020 | 0.0037 | -0.0049 |
| 23 | -10.664 | -1.6156 | 0.0668 | 0.6673 | -0.4323 | 0.0330 | -0.0115 | -0.0423 | 0.1019 | -0.0316 | -0.1892 | 0.1512 |
| 24 | -4.62475 | -0.8476 | 0.4114 | 1.8519 | -0.7076 | -0.4103 | 0.3150 | 0.0241 | -0.2358 | 0.1033 | 0.2747 | -0.1665 |
| 25 | 5.6829 | 0.8956 | 0.2010 | 1.3296 | 0.4402 | 0.0833 | -0.2704 | -0.0298 | -0.0046 | 0.3232 | -0.0096 | -0.2766 |
| 26 | -1.84347 | -0.3528 | 0.4917 | 2.5777 | -0.3529 | 0.0335 | -0.0051 | -0.0208 | 0.1748 | -0.1384 | 0.1248 | -0.2072 |
| 27 | 2.85964 | 0.4364 | 0.1708 | 1.5498 | 0.1981 | -0.0731 | -0.0765 | -0.0136 | 0.1010 | 0.1046 | -0.0034 | -0.0707 |
| 28 | -8.04535 | -1.2709 | 0.1763 | 1.0093 | -0.5331 | -0.0257 | -0.1420 | 0.0235 | 0.0229 | 0.3723 | -0.3609 | -0.1046 |
| 29 | 7.33947 | 1.1333 | 0.1503 | 1.0801 | 0.4778 | -0.1476 | 0.1304 | 0.1335 | -0.0169 | -0.0022 | -0.1264 | 0.1537 |
| 30 | 5.1215 | 0.8347 | 0.2896 | 1.5288 | 0.5457 | -0.0271 | 0.4095 | -0.4015 | 0.0463 | -0.2153 | 0.1058 | 0.0711 |

DURBIN-WATSON D 1.795
1ST ORDER AUTOCORRELATION 0.062

PLOT OF YRES*COUNT LEGEND: A = 1 OBS, B = 2 OBS, ETC.



# SUPPLY/DEMAND BALANCING

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## ENERGY SUPPLY/DEMAND BALANCING
## OUTLINE

- BASE YEAR BALANCE
- PROJECTING FUTURE BALANCES
- MODELING APPROACHES

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BASE YEAR BALANCE

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## THE BASE YEAR BALANCE HAS AN IMPORTANT ROLE

- INTEGRATE HISTORICAL DATA ON ENERGY SUPPLY AND DEMAND FLOWS
  - ENERGY NETWORK
  - DATA GAPS, INCONSISTENCIES

- PROVIDES A FRAMEWORK FOR PROJECTING FUTURE ENERGY FLOWS
  - BASIS FOR PROJECTIONS
  - TOOL FOR ANALYZING PLANNING ISSUES

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## ENERGY NETWORK REPRESENTS ENERGY FLOWS FROM SUPPLY TO DEMAND

- DISAGGREGATE ENERGY SECTOR INTO ACTIVITIES AND FLOWS
- ACTIVITIES
  - ENERGY RESOURCE PRODUCTION, IMPORTATION
  - PROCESSING
  - TRANSPORT, DISTRIBUTION
  - UTILIZATION
- LEVEL OF DISAGGREGATION DEPENDS ON THE USE FOR THE NETWORK

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## CONSIDERATIONS IN NETWORK DESIGN

- LEVEL OF DETAIL
  - DEMAND SUBSECTORS
  - PROCESS TYPES
  - REGIONALIZATION
- DATA
  - AVAILABILITY
  - TIME REQUIREMENTS FOR COLLECTION, PROCESSING AND ANALYSIS

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## ESTABLISHING A BASE YEAR NETWORK BALANCE IS AN ITERATIVE PROCESS

- COMPILE DATA
- IDENTIFY INCONSISTENCIES AND GAPS
- COLLECT DATA
- MAKE ASSUMPTIONS

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PROJECTING FUTURE ENERGY BALANCES

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## METHODS OF PROJECTING FUTURE SUPPLY/DEMAND BALANCES

- MANUAL BALANCING
- ACCOUNTING MODELS (COMPUTERIZED MANUAL BALANCING)
- ENERGY SECTOR MODELS

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## ENERGY SUPPLY/DEMAND BALANCE PROBLEM FOR FUTURE YEARS

**PRESENT**

- BASE YEAR ENERGY SUPPLY/DEMAND BALANCE

**FUTURE**

- ENERGY DEMAND
- ENERGY IMPORT PRICES
- RESERVES AND COSTS OF ENERGY RESOURCES
- AVAILABILITY AND COST OF ENERGY TECHNOLOGIES
- GOVERNMENT POLICIES
- STRATEGIES

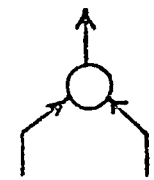
ENERGY SUPPLY/DEMAND BALANCE PROCEDURE

**FUTURE ENERGY SUPPLY/DEMAND BALANCES**

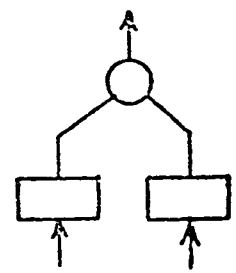
- QUANTITIES OF ENERGY FLOWS
- COSTS AND PRICES OF ENERGY FLOWS

## FUEL CHOICE DECISION POINTS ARE EMBEDDED IN THE NETWORK

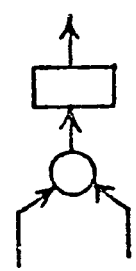
FUEL SUBSTITUTION



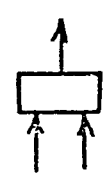
FUEL/TECHNOLOGY SUBSTITUTION



FUEL SUBSTITUTION FOR GIVEN TECHNOLOGY



FUEL COMPLEMENTARITY



→ FUEL, ▭ TECHNOLOGY, ○ DECISION POINT

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## MANUAL BALANCING MECHANICS

- START WITH BASE YEAR SUPPLY/DEMAND BALANCE
- PROJECT ENERGY DEMANDS
- ESTIMATE PROCESS THERMAL EFFICIENCIES
- BACKTRACK DEMANDS THROUGH NETWORK PROCESSES
- ESTIMATE ENERGY FLOWS AT NETWORK BRANCH POINTS

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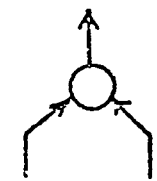
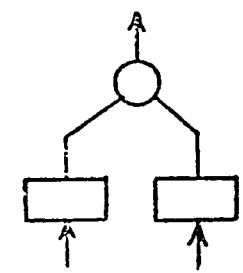
## FUEL CHOICE DECISION POINTS ARE EMBEDDED IN THE NETWORK

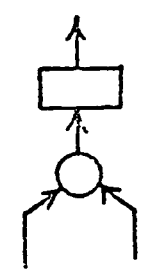
FUEL SUBSTITUTION



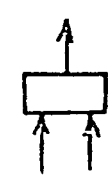
FUEL/TECHNOLOGY SUBSTITUTION



FUEL SUBSTITUTION FOR GIVEN TECHNOLOGY



FUEL COMPLEMENTARITY



→ FUEL, ▭ TECHNOLOGY, ○ DECISION POINT

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## MANUAL BALANCING MECHANICS

- START WITH BASE YEAR SUPPLY/DEMAND BALANCE
- PROJECT ENERGY DEMANDS
- ESTIMATE PROCESS THERMAL EFFICIENCIES
- BACKTRACK DEMANDS THROUGH NETWORK PROCESSES
- ESTIMATE ENERGY FLOWS AT NETWORK BRANCH POINTS

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## FACTORS CONSIDERED IN ESTIMATING ENERGY FLOWS AT BRANCH POINTS

- MARKET RESPONSE
  - RELATIVE FUEL PRICES
  - GOVERNMENT CONTROL OF PRICES AND/OR QUANTITIES
- GOVERNMENT OBJECTIVES
  - PRIORITY TO DOMESTIC RATHER THAN IMPORTED FUELS
  - PRIORITY TO LABOR-INTENSIVE ENERGY ACTIVITIES
  - PRIORITY FUEL ALLOCATIONS TO PARTICULAR ENERGY-USING SECTORS

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## MANUAL BALANCING VS ENERGY MODEL

- AFOREMENTIONED FACTORS CONSIDERED IMPLICITLY IN MANUAL BALANCE AND ACCOUNTING MODEL.

- FACTORS CONSIDERED EXPLICITLY IN ENERGY SECTOR MODEL

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MODELING APPROACHES

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## ENERGY COST IS MOST COMMON BASIS FOR ESTIMATING ENERGY FLOWS

- ADDITIONAL DATA NEEDED
- TECHNOLOGY PARAMETERS
- FUEL IMPORT AND DOMESTIC RESOURCE PRICES

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## CONVERSION PROCESS DATA

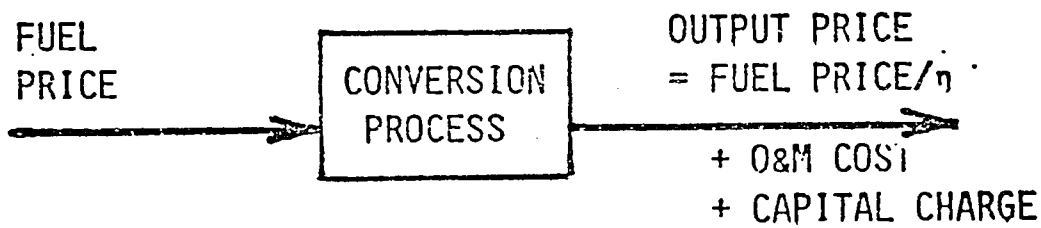
CAPITAL COST OF REPRESENTATIVE FACILITY ($)

CAPACITY (MMBTU/YR)

OPERATING & MAINTENANCE COST (NON-FUEL) ($/YR)

THERMAL EFFICIENCY

LEAD TIME (YRS)

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## PREDICTIVE VS. NORMATIVE MODELING APPROACHES

- PREDICTIVE
  - WHAT WILL HAPPEN GIVEN ASSUMPTIONS
  - ASSUMES GOVERNMENT HAS LIMITED CONTROL
- NORMATIVE
  - WHAT SHOULD HAPPEN GIVEN GOVERNMENT OBJECTIVES
  - ASSUMES GOVERNMENT HAS TOTAL CONTROL

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## PREDICTIVE MODELS

- EQUILIBRIUM
- SIMULATION

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## EQUILIBRIUM MODEL

- SET OF EQUATIONS REPRESENTING ENERGY QUANTITIES AND PRICES
- SOLVE FOR EQUILIBRIUM QUANTITIES AND PRICES
- INCLUDE GOVERNMENT REGULATION AND DECENTRALIZED OBJECTIVES

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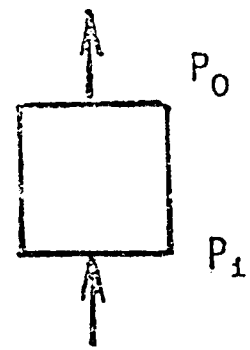
## EQUILIBRIUM MODEL CONVERSION PROCESS EXAMPLE

$Q_0 = Q_i \times e$




$P_0 = P_i + \frac{O\&M}{e}$ + CAPITAL COST TERM

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NORMATIVE MODELS

- LINEAR PROGRAMS (QUALIFIED)
- MULTI-OBJECTIVE PROGRAMS

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## LINEAR PROGRAM

OBJECTIVE:

MIN TOTAL COST: $\sum_{I,J} c_I X_{IJ}$

CONSTRAINTS: $\sum_J A_{IJ} X_{IJ} = B_I \quad I = 1,2,..n$

(DEMAND, CAPACITY, CHANGE RATE, ETC.)

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## EQUILIBRIUM MODELS

- ADVANTAGES
  - FLEXIBLE AT REPRESENTING COMPLEX PRICING POLICIES
  - DECENTRALIZED OBJECTIVES ARE EASILY EMBEDDED IN NETWORK
  - MARKET SHARE DISTRIBUTION NOT LEAST COST
- DISADVANTAGES
  - CONSTRAINTS DIFFICULT TO MODEL
  - MODEL SOLUTION SOMETIMES DIFFICULT TO SOLVE FOR

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## LINEAR PROGRAM

- ADVANTAGES
  - CONSTRAINTS HANDLED EASILY
  - MODEL SOLUTION IS ROUTINE
- DISADVANTAGES
  - PRICING POLICIES VERY DIFFICULT TO HANDLE
  - ASSUMES GOVERNMENT CONTROL OVER ALL PRICES AND QUANTITIES
  - KNIFE-EDGE SOLUTION CHARACTERISTICS
  - LEAST COST SUPPLY ASSUMPTION

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## DYNAMIC MODELS LINK SOLUTIONS THROUGH TIME

- CAPACITY IN PLACE
- MARKET SHIFTS

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SUMMARY:

IMPORTANT ASPECTS OF ENERGY MODELS

- ACCOUNTING/COST BASED
- NORMATIVE/PREDICTIVE
- STATIC/DYNAMIC
- LEAST COST SOURCE/ALLOCATION MIX

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## CONSIDERATIONS IN SELECTING AN ENERGY MODEL

- CAPABILITY TO ADDRESS THE PARTICULAR ENERGY PLANNING ISSUES
- EASE OF UNDERSTANDING THE WORKINGS OF THE MODEL (AND INTERPRETING THE RESULTS)
- RESOURCE REQUIREMENTS TO IMPLEMENT THE MODEL

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## AGRICULTURE END USE DEVICES

- MOBILE SOURCE
- CROP DRYING
- IRRIGATION & DRAINAGE PUMPS
- LIGHTING
- NON-ENERGY

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## Comparison of Base-Year Efficiencies of Agricultural-Sector End-Use Devices with Moderate and Enhanced Conservation

| Category of Useful Energy Demand | End-Use Device[a] | Base-Year Efficiency[b] ($\eta_B$) | Moderate Conservation Efficiency[b,c] ($\eta_M$) | Technical Change Limit[d] ($\eta_M/\eta_B$) | Enhanced Conservation Efficiency[b,c] ($\eta_E$) | Technical Change Limit[d] ($\eta_E/\eta_B$) | Improvement of $\eta_E$ over $\eta_M$ (%) |
|---|---|---|---|---|---|---|---|
| Direct Heat - Any Fuel | Distillate Oil Crop Dryer | 0.60 | 0.65 | 1.08 | 0.70 | 1.17 | 8 |
| | Solar Crop[b] Dryer with Distillate Backup[e] | 0.93 | 0.96 | 1.0 | 0.96 | 1.0 | 0 |
| Electrochemical and Lighting | Electric Device | 0.58 | 0.60 | 1.03 | 0.63 | 1.09 | 5 |
| Mechanical Drive | Distillate-Fired Engine | 0.34 | 0.36 | 1.06 | 0.39 | 1.15 | 8 |

[a]Device efficiency data have been aggregated into generic categories from a disaggregated data set.

[b]$\eta$ is the efficiency of the device and is the ratio of energy out (useful energy) to energy in (energy consumed).

[c]Efficiencies listed are the maximum obtainable for the conservation strategy. These efficiencies are applicable to new and replacement capacity of the device over the growth period.

[d]The ratio of the efficiency with conservation to the base-year efficiency; this is the maximum improvement achievable under the conservation assumption.

[e]The efficiency of the solar device with backup is a combined efficiency of both devices based on the shares of solar and backup usage.

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## PROCESS EQUATIONS FOR NETWORK EXAMPLE

NOTE: $P_i$ = price on input link of process
$P_o$ = price on output link of process
$Q_i$ = quantity on input link of process
$Q_o$ = quantity on output link of process

RS1 (Resource Process 1)

$$P_o = 5 + .5\ Q_o + .02\ Q_o^2$$

RS2 (Resource Process 2)

$$P_o = 34.77$$

PP1 (Pricing Process)

$$P_o = .8\ P_i$$
$$Q_o = Q_i$$

DEC1 (Decision Process)

$$P_o = P_{i(link\ 1)}\ S_{link1} + P_{i(link3)}\ S_{link3}$$

where $$S_{link1} = \left(\frac{1}{P_{i(link1)}}\right)^r \Big/ \left[\left(\frac{1}{P_{i(link1)}}\right)^r + \left(\frac{1}{P_{i(link3)}}\right)^r\right]$$

$$S_{link3} = \left(\frac{1}{P_{i(link3)}}\right)^r \Big/ \left[\ .\ .\ .\ \right]$$

$$Q_o = Q_{i(link1)} + Q_{i(link3)}$$

PR1 (Conversion Process)

$$P_o = \frac{P_i}{n} + OM + \left[\frac{TCI}{CAPM}\right]\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

$$Q_o = Q_i n$$

DEM1 (Demand Process)

$$Q_i = 500/P_i$$

## DATA FOR NETWORK EXAMPLE

RS1 (Resource Process 1)

$$P_2 = 5 + .5\ Q_2 + .02\ Q_2^2$$

RS2 (Resource Process 2)

Supply Curve: $P = 34.77$

PP1 (Pricing Process)

Price Multiplier = .8

DEC1 (Decision Process)

Price Sensitivity Parameter: $r = 1.0$

PR1 (Conversion Process)

| | |
|---|---|
| Efficiency: | $n = .77$ |
| O&M Cost: | $OM = 1.5$ |
| Total Capital Cost: | $TCI = 16{,}900$ |
| Capacity of Plant: | $CAPM = 803.4$ |
| Plant Life: | $n = 30$ |
| Interest Rate: | $i = .10$ |
| Capital Recovery Factor | $CRF_i^n = .10608$ |

DEM1 (Demand Process)

Demand Curve: $Q = 500/P$

## ITERATION PROCEDURE FOR EXAMPLE NETWORK

Start with assumed values of output quantities of the resource processes:

$Q_1$ = 100 (Resource process 2)

$Q_2$ = 10 (Resource process 1)

link nos.

### UP-PASS PRICE EQUATIONS:

RS1:

$$P_2 = 5 + .5\ Q_2 + .02\ Q_2^2$$

RS2:

$$P_1 = 34.77$$

PP1:

$$P_3 = .8\ P_2$$

DEC1:

$$P_4 = P_1\ S_1 + P_3\ S_3$$

where $S_1 = (1/P_1)^r/[(1/P_1)^r + (1/P_3)^r]$

$S_3 = (1/P_3)^r/[\ .\ .\ .\ ]$

PR1:

$$P_5 = \frac{P_4}{.77} + 1.5 + \left(\frac{16900}{803.4}\right)\ .10608$$

END OF UP-PASS.//

### DOWN-PASS QUANTITY EQUATIONS:

DEM 1

$$Q_5 = 500/P_5$$

PRI:

$$Q_4 = Q_5/.77$$

DEC1:

$Q_1^* = Q/_4 S_1$ where $S_1$ is computed as in the up-pass

$Q_3 = Q_4 S_3$ where $S_3$ is computed as in the up-pass

PP1:

$Q_2^* = Q_3$

END OF DOWN-PASS.//

END OF ITERATION

1. Compare $Q_1 \stackrel{?}{=} Q_1$

   $Q_2 \stackrel{?}{=} Q_2$

2. If equal, these prices and quantities constitute an equilibrium solution. STOP.

3. If not equal, adjust $Q_1$ and $Q_2$, and begin another up-pass.

## ITERATION RESULTS FOR NETWORK EXAMPLE

### Iteration 1

Assume $Q_1 = 100$ $Q_2 = 10$

| | |
|---|---|
| $P_1 = 34.77$ | $Q_1^* = 3.357$ |
| $P_2 = 12.4929$ | $Q_2^* = 11.677$ |
| $P_3 = 9.9944$ | $Q_3 = 11.677$ |
| $P_4 = 30.3847$ | $Q_4 = 15.034$ |
| $P_5 = 43.1921$ | $Q5 = 11.575$ |

### Iteration 10 (Converged Solution)

Adjusted $Q_1 = 6.318$, $Q_2 = 15.520$

| | |
|---|---|
| $P_1 = 34.77$ | $Q_1^* = 6.282$ |
| $P_2 = 17.5771$ | $Q_2^* = 15.534$ |
| $P_3 = 14.0617$ | $Q_3 = 15.534$ |
| $P_4 = 20.9458$ | $Q_4 = 21.816$ |
| $P_5 = 20.7651$ | $Q_5 = 16.798$ |

$Q_1 = Q_1^*$ and $Q_2 = Q_2^*$; STOP

### SOLUTION FOR r = 15 (least cost source)

| | |
|---|---|
| $P_1 = 34.770$ | $Q_1 = 0.0006$ |
| $P_2 = 25.1915$ | $Q_2 = 21.674$ |
| $P_3 = 20.1532$ | $Q_3 = 21.674$ |
| $P_4 = 20.1897$ | $Q_4 = 21.680$ |
| $P_5 = 29.9518$ | $Q_5 = 16.694$ |

### SOLUTION FOR r = 1.0 and priority on resource production of resource 2 (capacity = 10.0).

| | |
|---|---|
| $P_1 = 34.770$ | $Q_1 = 10.0$ |
| $P_2 = 11.8292$ | $Q_2 = 9.963$ |
| $P_3 = 9.5362$ | $Q_3 = 9.963$ |
| $P_4 = 22.1717$ | $Q_4 = 19.963$ |
| $P_5 = 32.5271$ | $Q_5 = 15.372$ |

## DATA FOR NETWORK EXAMPLE

RS1 (Resource Process 1)

$$P_2 = 5 + .5\ Q_2 + .02\ Q_2^2$$

RS2 (Resource Process 2)

Supply Curve: $P = 34.77$

PP1 (Pricing Process)

Price Multiplier = .8

DEC1 (Decision Process)

Price Sensitivity Parameter: $r = 1.0$

PR1 (Conversion Process)

| | |
|---|---|
| Efficiency: | $n = .77$ |
| O&M Cost: | $OM = 1.5$ |
| Total Capital Cost: | $TCI = 16{,}900$ |
| Capacity of Plant: | $CAPM = 803.4$ |
| Plant Life: | $n = 30$ |
| Interest Rate: | $i = .10$ |
| Capital Recovery Factor | $CRF_i^n = .10608$ |

DEM1 (Demand Process)

Demand Curve: $Q = 500/P$

DEC1:

$Q_1^* = Q/_4 S_1$ where $S_1$ is computed as in the up-pass

$Q_3 = Q_4 S_3$ where $S_3$ is computed as in the up-pass

PP1:

$Q_2^* = Q_3$

END OF DOWN-PASS.//

END OF ITERATION

1. Compare $Q_1 \stackrel{?}{=} Q_1$

   $Q_2 \stackrel{?}{=} Q_2$

2. If equal, these prices and quantities constitute an equilibrium solution. STOP.

3. If not equal, adjust $Q_1$ and $Q_2$, and begin another up-pass.

## ITERATION PROCEDURE FOR EXAMPLE NETWORK

Start with assumed values of output quantities of the resource processes:

$Q_1 = 100$ (Resource process 2)

$Q_2 = 10$ (Resource process 1)

link nos.

UP-PASS PRICE EQUATIONS:

RS1:

$$P_2 = 5 + .5\ Q_2 + .02\ Q_2^2$$

RS2:

$$P_1 = 34.77$$

PP1:

$$P_3 = .8\ P_2$$

DEC1:

$$P_4 = P_1\ S_1 + P_3\ S_3$$

where $S_1 = (1/P_1)^r/[(1/P_1)^r + (1/P_3)^r]$

$S_3 = (1/P_3)^r/[\ .\ .\ .\ ]$

PR1:

$$P_5 = \frac{P_4}{.77} + 1.5 + \frac{16900}{803.4}\ .10608$$

END OF UP-PASS.//

DOWN-PASS QUANTITY EQUATIONS:

DEM 1

$$Q_5 = 500/P_5$$

PRI:

$$Q_4 = Q_5/.77$$

DEC1:

$Q_1^* = Q/_4 S_1$ where $S_1$ is computed as in the up-pass

$Q_3 = Q_4 S_3$ where $S_3$ is computed as in the up-pass

PP1:

$Q_2^* = Q_3$

END OF DOWN-PASS.//

END OF ITERATION

1. Compare $Q_1 \stackrel{?}{=} Q_1$

   $Q_2 \stackrel{?}{=} Q_2$

2. If equal, these prices and quantities const

# ELECTRIC POWER SYSTEMS

WILLIAM A. BUEHRING
ARGONNE NATIONAL LABORATORY

MAY 24, 1985

THE MATERIAL FOR TODAY FOCUSES ON ELECTRIC GENERATION PLANNING ISSUES...

- o OVERVIEW OF ELECTRIC SYSTEM PLANNING
- o KEY DEFINITIONS
- o PROBLEM SESSION
- o GENERATION PLANNING PROCESS
- o WIEN AUTOMATIC SYSTEM PLANNING (WASP)
- o SCREENING CURVES
- o PROBLEM SESSION

ELECTRIC SYSTEM PLANNING IS LINKED TO OVERALL ENERGY PLANNING PRIMARILY THROUGH THE DEMAND FORECAST

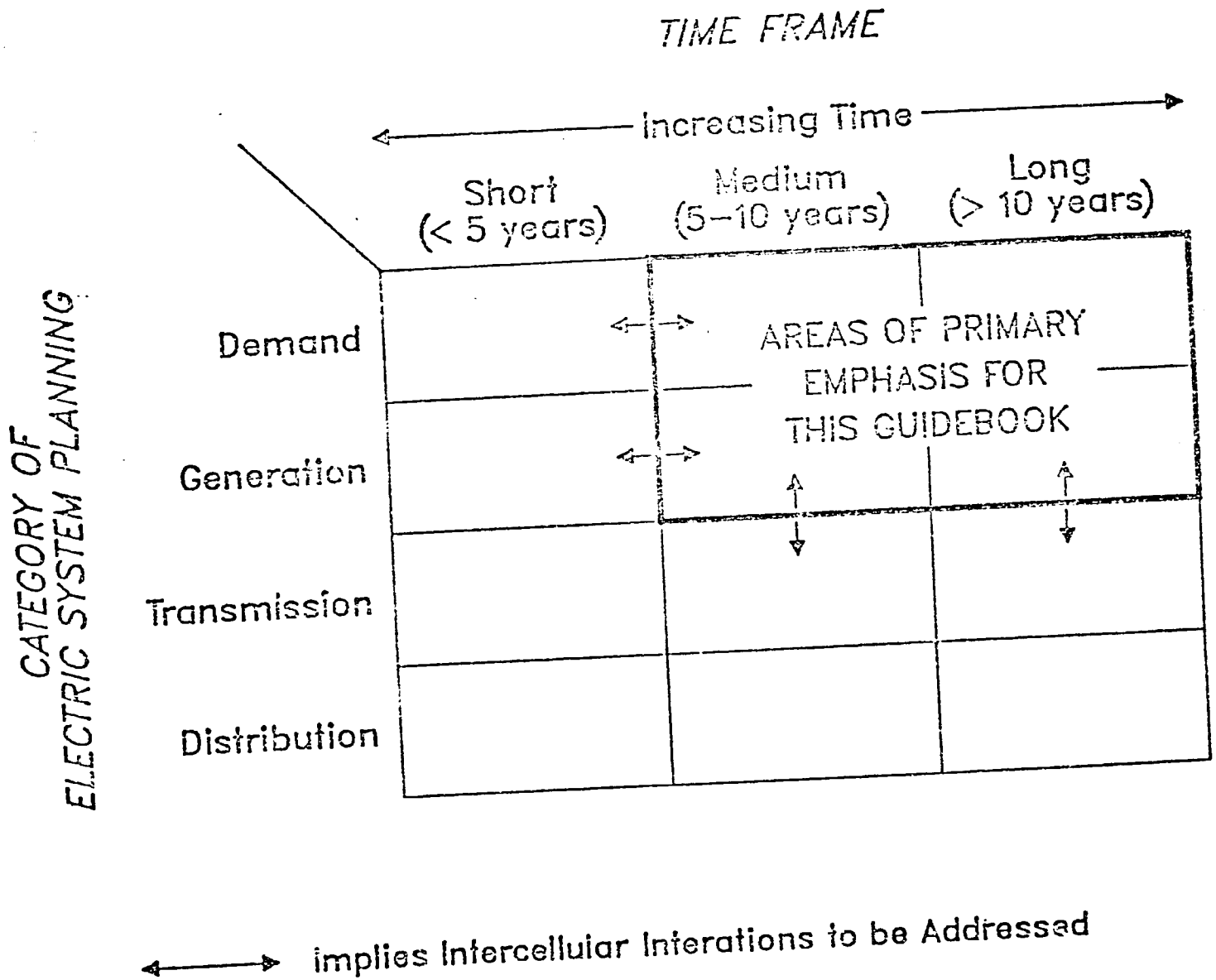
ADDITIONAL CONNECTIONS:

- FINANCIAL ANALYSIS
- RESOURCE USE

BENEFITS OF LINKAGE:

- AVOID EFFORT DUPLICATION
- PROVIDE CONSISTENT ASSUMPTIONS FOR MAJOR INDEPENDENT VARIABLES, SUCH AS POPULATION GROWTH
- DEVELOP UNDERSTANDING FOR BASIS OF FORECAST

ELECTRIC SYSTEM PLANNING ENCOMPASSES A BROAD COLLECTION OF ACTIVITIES SPANNING SEVERAL TIME HORIZONS



THE PRIMARY OBJECTIVE OF A PUBLIC UTILITY COMPANY IS TO ADEQUATELY MEET DEMAND AT MINIMUM COST

- MEANING OF "ADEQUATELY"

- CONSTRAINTS

  - FINANCIAL
  - RESOURCE
  - TECHNICAL
  - ENVIRONMENTAL
  - POLITICAL
  - INFRASTRUCTURE

FOUR BASIC QUESTIONS MUST BE ANSWERED
IN THE PLANNING PROCESS

1. <u>WHAT</u> CAPACITIES TO INSTALL TO ENSURE AN APPROPRIATE LEVEL OF RELIABILITY?

2. <u>HOW</u> TO PICK THE BEST COMBINATION AMONG THE DIFFEREN TECHNOLOGIES AT HAND NOW AND LATER ON?

3. <u>WHERE</u> TO LOCATE THIS EQUIPMENT?

4. <u>WHEN</u> IS THE PROPER TIME TO INCORPORATE THEM INTO TH SYSTEM?

SYSTEM PLANNERS FACE NUMEROUS COMPLEXITIES

- COORDINATION OF SYSTEM PLANNING CATEGORIES

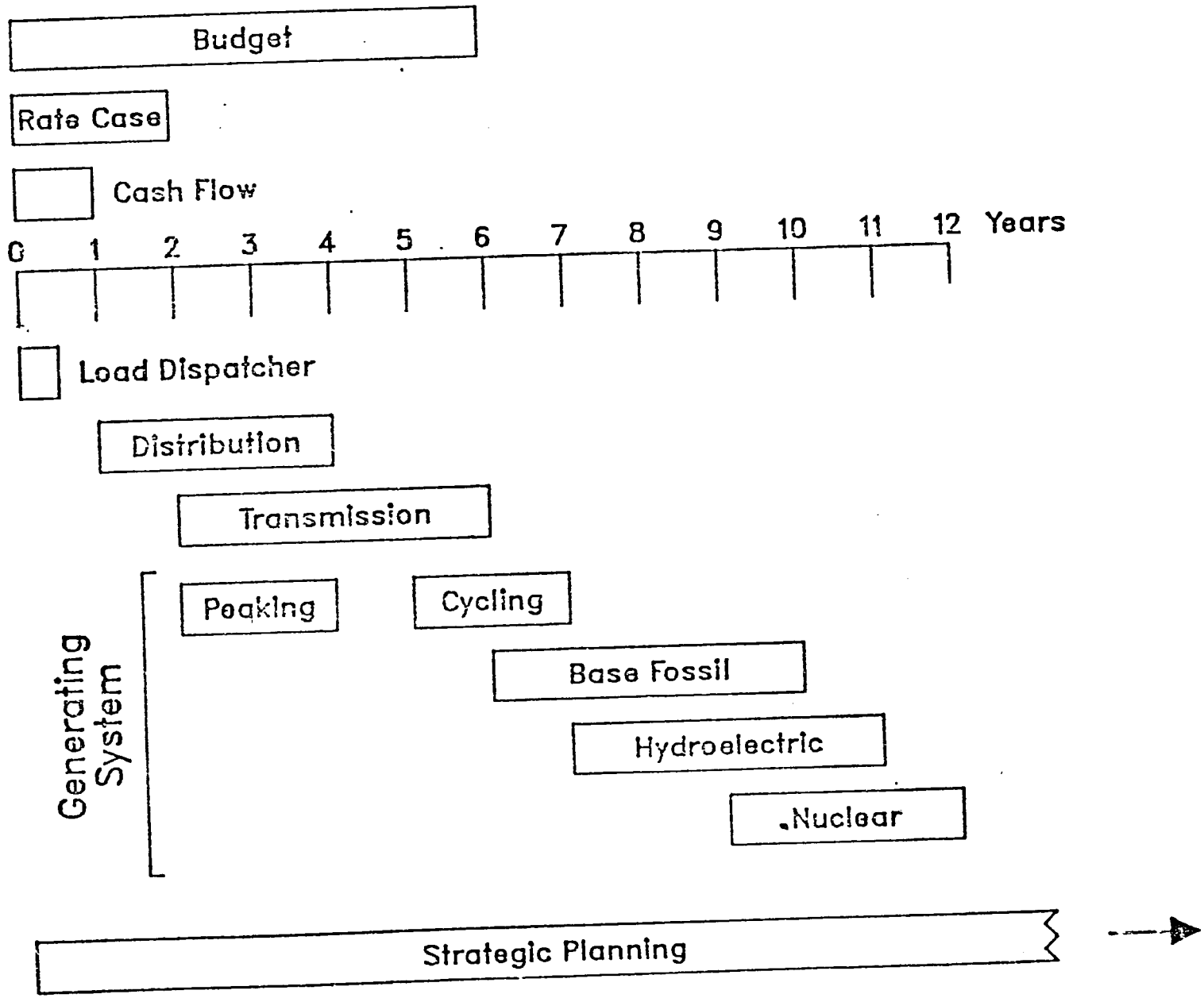
- UNCERTAINTIES
  - DEMAND
  - TECHNOLOGY PERFORMANCE
  - FUEL AVAILABILITY AND COST
  - FINANCIAL CONDITIONS

- LONG TIME HORIZONS

- ENORMOUS NUMBER OF ALTERNATIVE LONG-TERM EXPANSION PATHWAYS

- GIVEN A PARTICULAR GENERATING SYSTEM CONFIGURATION, SYSTEM OPERATION MUST BE OPTIMIZED

VARIOUS TYPES OF PLANNING REQUIRE DIFFERENT TIME HORIZONS



UTILITY DEVELOPMENT PHILOSOPHY SHOULD BE CLEARLY STATED

- ISOLATED VS. INTERCONNECTED OPERATIONS
  - EMERGENCY SUPPLY
  - INTERRUPTIBLE EXCHANGE
  - JOINT PLANNING
  - SHORT-TERM PURCHASES/SALES
  - ENTITLEMENT ARRANGEMENTS
  - JOINT OWNERSHIP
- EXTERNAL CONSIDERATIONS

MAJOR ISSUES MUST BE ADDRESSED IN DEVELOPING A LONG-RUN EXPANSION PLAN FOR THE GENERATING SYSTEM

- DEMAND
- TECHNOLOGY
- ECONOMIC
- RELIABILITY
- PRACTICAL CONSTRAINTS

THE DEMAND FORECAST IS CLEARLY ONE OF THE MOST IMPORTANT PARTS OF GENERATING SYSTEM ANALYSIS

- POWER (KW)
- ENERGY (KWH)
- LOAD VARIATIONS OVER TIME
- RANDOMNESS OF LOAD
- ERRORS IN FUTURE ESTIMATED DEMAND

VARIOUS TECHNOLOGIES ARE CURRENTLY AVAILABLE AS CANDIDATES FOR EXPANSION OF GENERATING SYSTEMS

- NUCLEAR
- FOSSIL
- HYDROELECTRIC
- COMBUSTION TURBINES
- DIESEL ENGINES
- COMBINED CYCLE
- PUMPED STORAGE

THE PLANNER MUST ALSO CONSIDER POTENTIAL FUTURE OPTIONS.

- STEAM (WOOD, SOLAR, GEOTHERMAL, ETC.)
- FUEL CELLS
- PHOTOVOLTAIC
- WIND TURBINES
- OCEAN THERMAL ENERGY CONVERSION
- TIDAL POWER
- STORAGE (BATTERY, COMPRESSED AIR)

A FUNDAMENTAL ASPECT OF ANY ECONOMIC EVALUATION IS THE TIME ELEMENT

- 30-45 YEARS FOR ANALYSIS
- TIME VALUE OF MONEY
  - INFLATION (DEFLATION)
  - REAL CHANGES OVER TIME
- SELECTION OF DISCOUNT RATE
  - NECESSARY FOR COMPARING ALTERNATIVES
  - RESULTS ARE CLEARLY SENSITIVE
  - SCARCITY OF CAPITAL

THE LEVEL OF ADEQUACY FOR MEETING DEMAND IS ANOTHER IMPORTANT ISSUE

- RANDOM BREAKDOWNS
- DEMAND VARIATION
- HYDROELECTRIC VARIATION
- SCHEDULED MAINTENANCE
- NUCLEAR REFUELING
- CHANGES IN NEW CAPACITY AVAILABILITY

METHODS FOR INCLUDING SYSTEM RELIABILITY IN SYSTEM PLANNING VARY

- TECHNICAL CONSTRAINT
  - RESERVE MARGIN
  - LOLP
  - UNSERVED ENERGY
- COSTS OF DIFFERENT RELIABILITY LEVELS

ONCE A POTENTIAL GENERATION SOLUTION IS FOUND
OTHER CONSTRAINTS MUST BE CONSIDERED

- TRANSMISSION
- UNIT SIZE
- FUEL
- MANPOWER
- FINANCIAL
- ENVIRONMENTAL
- INFRASTRUCTURE
- SITING
- DISTRIBUTION

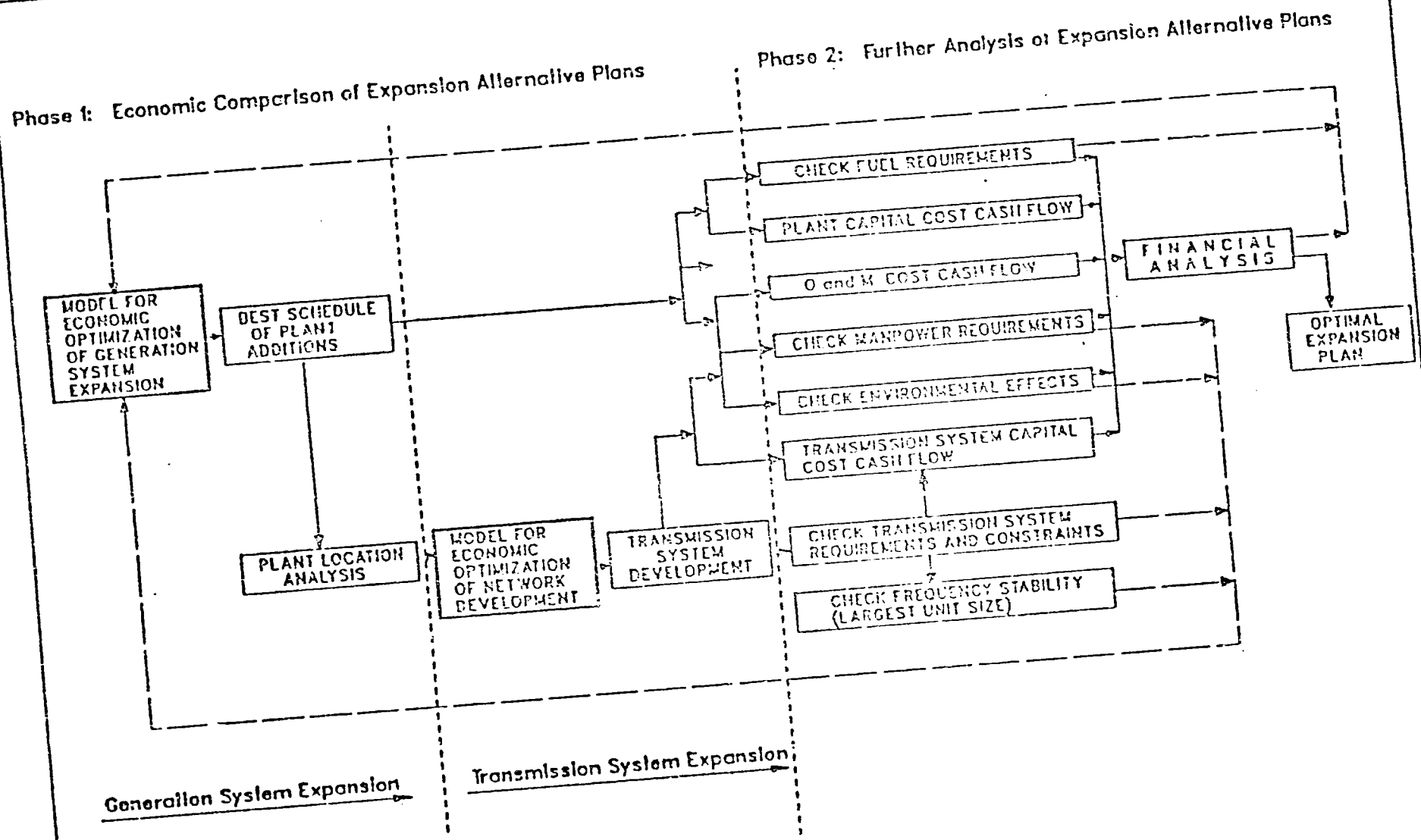



Figure 3.3 Schematic representation of the Planning Process and consideration of constraints

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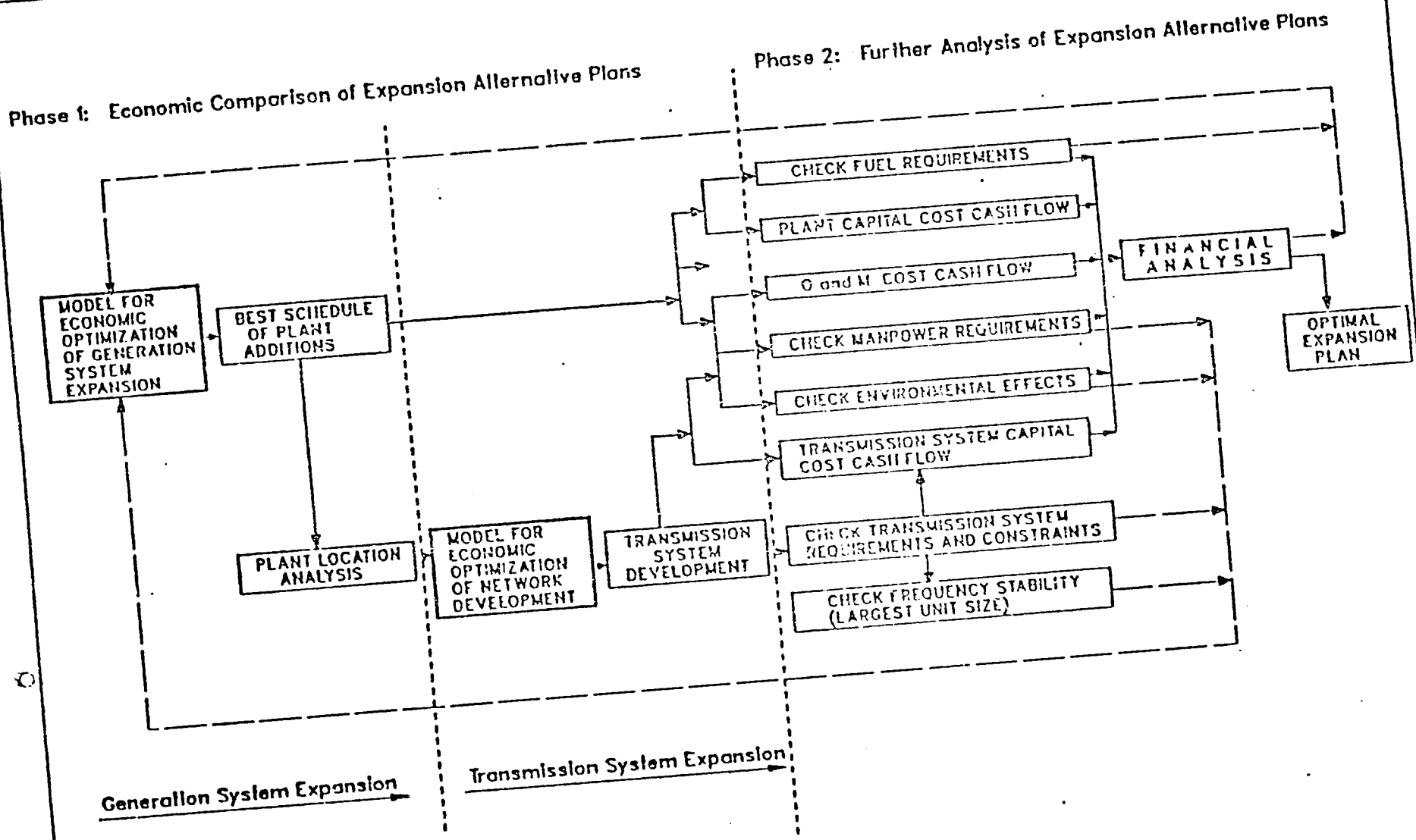


Figure 3.3 Schematic representation of the Planning Process and consideration of constraints

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THE FULL COMPLEXITIES OF ELECTRIC SYSTEM PLANNING MUST BE RECOGNIZED FOR BEST GENERATION ANALYSIS

- ELECTRIC VS. OVERALL ENERGY PLANNING
- DIMENSIONS OF ELECTRIC SYSTEM PLANNING
- ISSUES FOR ANALYSIS

# KEY DEFINITIONS

TO MAKE BEST USE OF THE INFORMATION PRESENTED IN THIS COURSE, WE NEED TO AGREE ON DEFINITIONS

- LOAD FACTOR
- CAPACITY FACTOR
- AVAILABILITY
- SCHEDULED MAINTENANCE
- FORCED OUTAGE
- HEAT RATE
- LOADING ORDER
- SPINNING RESERVE

LOAD FACTOR IS THE AVERAGE LOAD FACED BY A GENERATING SYSTEM

$$L.F. = \frac{\text{SYSTEM GENERATION}}{\text{PEAK LOAD} \times \text{PERIOD HOURS}}$$

- INCLUDES LOSSES (MUST BE CONSISTENT)
- NET OUTPUT OF GENERATING UNITS

ANNUAL LOAD FACTOR IS OFTEN VERY DIFFERENT FROM PERIOD LOAD FACTORS

$$\text{ANNUAL L.F.} = \frac{1}{N} \sum_{i=1}^{N} \frac{LF_i \times PL_i}{\text{ANNUAL PEAK LOAD}}$$

$N$ = NUMBER OF SEASONS

$PL_i$ = SEASON PEAK LOAD

$LF_i$ = SEASONAL LOAD FACTOR

CAPACITY FACTOR MEASURES OUTPUT OF A SINGLE GENERATING UNIT

$$\text{PERIOD CAPACITY FACTOR} = \frac{\text{TOTAL KWH GENERATED}}{\text{UNIT CAPACITY} \times \text{PERIOD HOURS}}$$

THE FORCED OUTAGE RATE IS A KEY CONSIDERATION IN GENERATION PLANNING

$$FOR = \frac{\text{FORCED OUTAGE HOURS}}{\text{GENERATION HOURS + FORCED OUTAGE HOURS}} \times 100\%$$

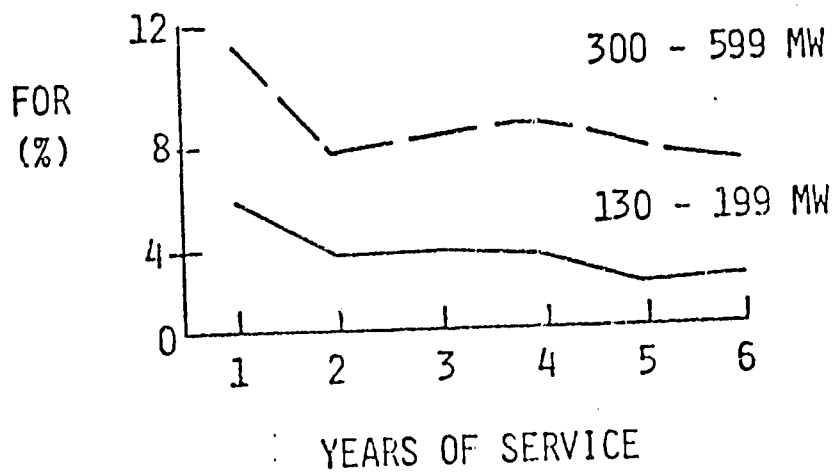
PLANNED OUTAGE RATE REFERS TO INSPECTION OR OVERHAUL OF MAJOR EQUIPMENT

- ANNUAL BOILER OVERHAUL
- 5 YEAR TURBINE OVERHAUL

MAINTENANCE OUTAGES ACCOUNT FOR SERVICE THAT CAN BE DEFERRED ONLY FOR A SHORT TIME

- OFTEN COMBINED WITH PLANNED OUTAGE TO YIELD COMPOSITE SCHEDULED OUTAGE RATE
- SOMETIMES PARTLY INCLUDED AS EQUIVALENT FORCED OUTAGE TIME BECAUSE OF RANDOMNESS

A PERIOD OF IMMATURITY IS OFTEN
ASSOCIATED WITH NEW UNITS



AVAILABILITY IS INFLUENCED BY MAINTENANCE, FORCED OUTAGE, AND REPAIR

TOTAL PERIOD HOURS (PH) =

SERVICE HOURS (SH) +

SCHEDULED OUTAGE HOURS (SOH) +

FORCED OUTAGE HOURS (FOH) +

RESERVE SHUTDOWN HOURS (RSH)

PH = SH + SOH + FOH + RSH

AVAILABLE HOURS INCLUDE SERVICE HOURS
AND RESERVE SHUTDOWN HOURS

$$AH = SH + RSH$$

AVAILABLE HOURS

PLANNED OUTAGE RATE IS

$$POR = \frac{SOH}{PH}$$

FULL FORCED OUTAGE RATE IS

$$FOR = \frac{FOH}{FOH + SH}$$

EQUIVALENT FORCED OUTAGE HOURS
ACCOUNTS FOR PARTIAL OUTAGES

$$EFOH = \sum_{i} . (\text{FORCED PARTIAL OUTAGE HOURS X PER-UNIT SIZE OF CAPACITY REDUCTION})$$

(DOES NOT INCLUDE FULL OUTAGES)

THE EQUIVALENT FORCED OUTAGE RATE ACCOUNTS FOR BOTH PARTIAL AND FULL OUTAGES

$$EFOR = \frac{FOH + EFOH}{SH + FOH}$$

THE EQUIVALENT AVAILABILITY IS DEFINED
IN TERMS OF POR AND EFOR

$$EA = (1 - POR) \times (1 - EFOR)$$

EA IS THE MAXIMUM CAPACITY ACHIEVABLE IN THE PERIOD

# PROBLEM SESSION

1. COMPUTE THE ANNUAL LOAD FACTOR FOR THE FOLLOWING CONDITIONS:

| SEASON | PEAK LOAD (MWE) | LOAD FACTOR |
|---|---|---|
| 1 | 1000 | .60 |
| 2 | 1200 | .57 |
| 3 | 1500 | .55 |
| 4 | 1000 | .60 |

2. COMPUTE AVAILABLE HOURS, EQUIVALENT FORCED OUTAGE HOURS, PLANNED OUTAGE RATE, FORCED OUTAGE RATE, EQUIVALENT FORCED OUTAGE RATE, EQUIVALENT AVAILABILITY, MAXIMUM CAPACITY FACTOR, AND MAXIMUM GENERATION IN KWH FOR A 100 MWE GENERATING UNIT UNDER THE FOLLOWING CONDITIONS:

1000 HOUR PERIOD (PH)

620 HOURS OF OPERATION (SH)

170 HOURS AVAILABLE BUT NOT CALLED ON (RSH)

150 PLANNED MAINTENANCE HOURS (SOH)

60 HOURS FULL FORCED OUTAGE (FOH)

50 HOURS DERATED OPERATION AT 40% POWER

20 HOURS DERATED OPERATION AT 50% POWER

# GENERATION PLANNING PROCESS

GENERATING PLANNING IS A COMPLEX PROCESS

- LOAD FORECAST
- EXISTING SYSTEM
- GENERATION RELIABILITY
- PRODUCTION SIMULATION
- INVESTMENT ANALYSIS
- LONG RANGE PLANNING MODEL
- FINANCIAL ANALYSIS
- JUDGMENTAL EVALUATION

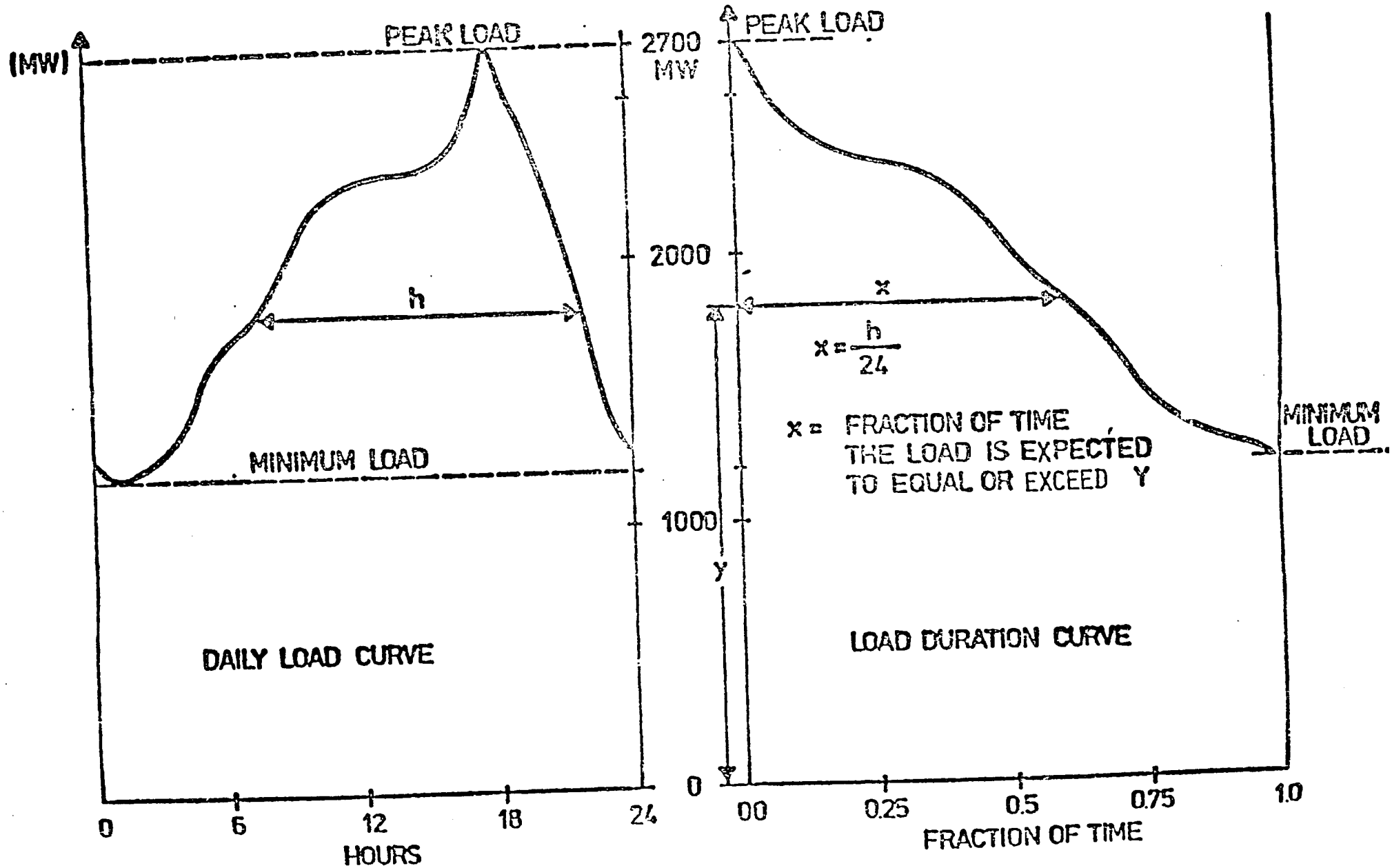
LOAD FORECASTING RELIES ON
TWO BASIC APPROACHES

1. <u>ENUMERATIVE</u> - IDENTIFY AND PROJECT USES OF ELECTRICITY

2. <u>ECONOMETRIC</u> - ASSOCIATE DEMAND WITH KEY ECONOMIC PARAMETERS, SUCH AS DISPOSABLE PERSONAL INCOME

(WEATHER ADJUSTMENTS ARE MADE IN BOTH METHODS)

THE LOAD DURATION CURVE IS OBTAINED BY ORDERING CHRONOLOGICAL LOAD DATA



THE LOAD DURATION CURVE IS SOMETIMES REPRESENTED AS A FIFTH-ORDER POLYNOMIAL:

$$Y = 1.0 + \sum_{I=1}^{5} A_I X^I$$

$$\text{MINIMUM LOAD} = 1.0 + \sum_{I=1}^{5} A_I$$

$$\text{LOAD FACTOR} = \int_0^1 F(X)\, DX$$

$$= 1.0 + \sum_{I=1}^{5} \frac{A_I}{I+I}$$

THE EXISTING SYSTEM HAS A SIGNIFICANT INFLUENCE ON PLANNING DECISIONS

- EXISTING UNITS
- COMMITTED ADDITIONS
- RETIREMENTS
- POWER POOL
- TRANSMISSION
- CHANGING PARAMETERS USUALLY MEAN NON-OPTIMUM STARTING POINT

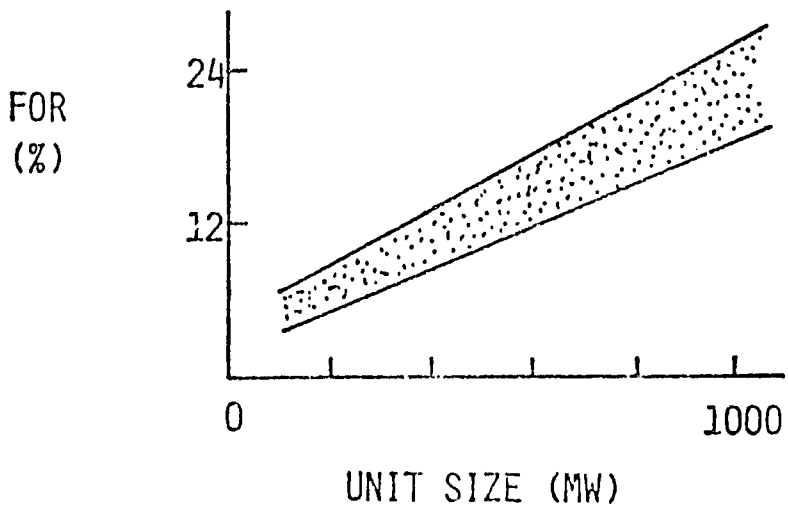
## COMPARISON OF ALTERNATIVES MUST ACCOUNT FOR DIFFERENCES IN GENERATION RELIABILITY

- FORCED OUTAGE RATE
- PLANNED OUTAGE RATE
- MAINTENANCE OUTAGE RATE
- RATE OF MATURING FOR NEW UNITS
- UNIT SIZE
- LEAD TIMES
- SYSTEM RELIABILITY INDEXES

UNIT SIZE SELECTION IS AS DIFFICULT AS SELECTING THE TYPE OF UNIT

- CAPITAL COST PER kW DECLINES AS UNIT SIZE INCREASES
- FORCED OUTAGE RATE USUALLY INCREASES WITH SIZE
- SPINNING RESERVE REQUIREMENTS

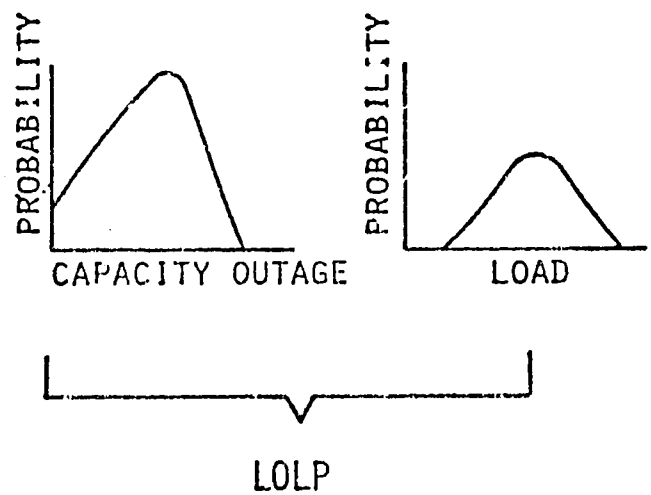
HISTORICAL DATA INDICATE FORCED OUTAGE RATE IS A FUNCTION OF UNIT SIZE



SYSTEM RELIABILITY INDEXES ARE MAJOR CRITERIA FOR DETERMINING CAPACITY NEEDS

- LOSS OF LOAD PROBABILITY (LOLP)
- LOSS OF ENERGY PROBABILITY (LOEP)

THE LOSS OF LOAD PROBABILITY IS THE PROPORTION OF TIME THE SYSTEM LOAD IS NOT MET



LOLP DOES NOT MEASURE HOW
OFTEN FAILURES OCCUR

ONE FAILURE/YR THAT LASTS ONE DAY

OR

120 FAILURES/YR THAT EACH LAST 12 MINUTES

ARE EQUIVALENT TO AN LOLP OF ONE DAY/YR

LOLP DOES NOT MEASURE HOW
OFTEN FAILURES OCCUR

ONE FAILURE/YR THAT LASTS ONE DAY

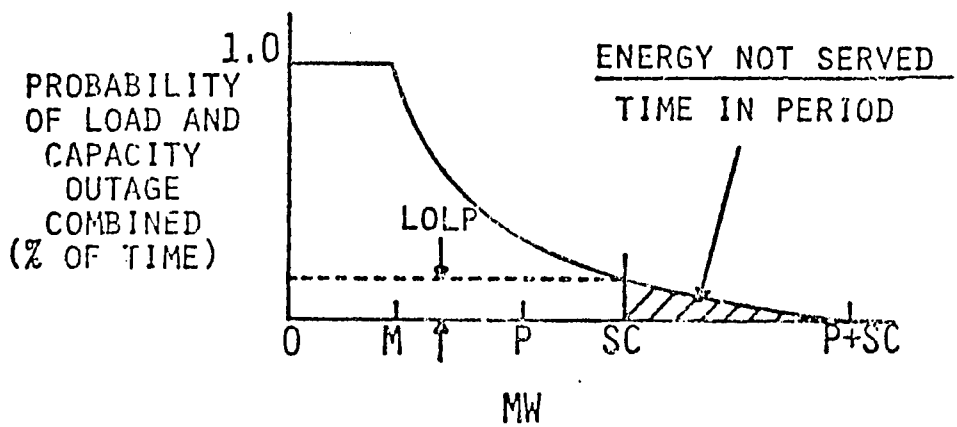
OR

120 FAILURES/YR THAT EACH LAST 12 MINUTES

ARE EQUIVALENT TO AN LOLP OF ONE DAY/YR

THE LOSS OF ENERGY PROBABILITY IS THE RATIO OF

ENERGY NOT SERVED TO TOTAL DEMAND




M = MINIMUM LOAD

P = PEAK LOAD

SC = TOTAL INSTALLED CAPACITY

THE PURPOSE OF PRODUCTION SIMULATION
IS TO DETERMINE THE EXPECTED
GENERATION FROM EACH UNIT

- UNIT HEAT RATES
- FUEL COSTS AND ESCALATION
- OPERATION AND MAINTNENANCE (O&M) COST
- FORCED OUTAGES
- SCHEDULED MAINTENANCE
- USE TOTAL VARIABLE COST TO DETERMINE LOADING ORDER (ECONOMIC DISPATCH)

THE ENERGY PRODUCED FROM ANY UNIT DEPENDS ON WHAT OTHER UNITS ARE IN THE SYSTEM

| GENERATOR (SIZE IN MWe) | VARIABLE COST (MILLS/KWH) | ECONOMIC LOADING ORDER |
|---|---|---|
| NUCLEAR (1000) | 6.3 | 1 |
| COAL ( 600) | 14.4 | 2 |
| COAL ( 200) | 14.9 | 3 |
| OIL ( 400) | 46.8 | 4 |
| COMBUSTION TURBINE ( 50) | 87.0 | 5 |

(SPINNING RESERVE CAN ALTER THE ORDER)

INVESTMENT ANALYSIS BRINGS IN THE CAPITAL COSTS OF THE ALTERNATIVES

- CAPITAL COST
- COST OF MONEY
- ESCALATION OF COST
- FIXED CHARGE RATE

COMPARING LEVELIZED GENERATION COSTS OF ALTERNATIVES IS NOT A SUFFICIENT EVALUATION:

- ENTIRE GENERATING SYSTEM MAY BE AFFECTED
- SIMPLE CLASSIFICATION (BASE-LOAD, ETC.) DOES NOT DETERMINE CAPACITY FACTORS
- ANALYSIS OF INTEGRATED SYSTEM IS COMPLEX

GENERATION PLANNING MODELS
ACCOUNT FOR THESE FACTORS

EXAMPLE: WIEN AUTOMATIC SYSTEM PLANNING PROGRAM (WASP)

OBJECTIVE: DETERMINE EXPANSION PLAN THAT MINIMIZES TOTAL DISCOUNTED COSTS OVER THE PLANNING HORIZON

FINANCIAL ANALYSIS IS NEEDED TO DETERMINE KEY ECONOMIC EFFECTS:

- o CASH FLOW
- o INTEREST COVERAGE RATIOS
- o REVENUE REQUIREMENTS
- o LONG-RUN MARGINAL COST

JUDGMENTAL EVALUATION IS USED TO INCLUDE NONECONOMIC FACTORS AND DECIDE:

- ENVIRONMENTAL EFFECTS
- FUEL AVAILABILITY
- NUCLEAR ISSUES
- REGULATORY IMPACT
- DIVERSIFICATION
- OVERALL RISKS
- FINANCING AVAILABILITY

CURRENT ELECTRIC GENERATING
TECHNOLOGIES ARE:

- NUCLEAR
- COAL STEAM
- OIL OR GAS STEAM
- HYDRO ELECTRIC
- COMBINED CYCLE
- COMBUSTION TURBINE

ADDITIONAL TECHNOLOGIES MAY
COMPETE IN THE COMING YEARS

- GASIFIED COAL COMBINED CYCLE
- FUEL CELL
- ATMOSPHERIC FLUIDIZED BED (COAL)
- PRESSURIZED FLUIDIZED BED
- WIND
- SOLAR THERMAL
- BREEDER REACTOR
- GEOTHERMAL
- SATELLITE POWER SYSTEMS

LIMITED STORAGE OPTIONS ARE AVAILABLE
TO ELECTRICAL UTILITIES

- HYDRO - WITH RESERVOIR
- PUMPED HYDRO
- BATTERIES
- COMPRESSED AIR
- CUSTOMER-SIDE THERMAL

## COMBUSTION TURBINES HAVE LOW FIXED COSTS AND HIGH OPERATING COSTS

| | |
|---|---|
| SIZE: | 50 - 100 MW |
| EFFICIENCY: | 24% |
| CAPITAL COST | $300 - 400/kW |
| VARIABLE COST: | 7¢/kWH |
| FORCED OUTAGE: | 10 - 20% |
| LEAD TIME: | 2 - 3 YEARS |
| LIFETIME: | 15 - 20 YEARS |

NUCLEAR UNITS HAVE HIGH FIXED COSTS AND LOW OPERATING COSTS

| | |
|---|---|
| SIZE: | 900 - 1300 MW |
| EFFICIENCY | 32% |
| CAPITAL COST: | $1500 - 3000/kW |
| TOTAL VARIABLE: | 1¢/kWH |
| FORCED OUTAGE: | 15 - 20% |
| LEAD TIME: | 10 - 14 YEARS |
| LIFETIME: | 30 YEARS |

# WIEN AUTOMATIC SYSTEM PLANNING (WASP) MODEL

## WASP ADDRESSES LONG-TERM PLANNING

## PERIODS UP TO 30 YEARS

1. DEMAND FORECASTS (SEASONAL)
2. TECHNICAL & ECONOMIC CHARACTERISTICS OF EXPANSION CANDIDATES
3. EXISTING & PLANNED SYSTEM
4. TECHNICAL & ECONOMIC PARAMETERS (INTEREST RATES, RELIABILITY)
5. OPERATING COSTS DEPEND ON PREVIOUS SELECTIONS

## THREE PLANNING PERIODS ARE DEFINED

1. PRE-PLANNING
   - EXISTING + COMMITTED UNITS

2. PLANNING PERIOD
   - START IS FIRST YEAR AN UNCOMMITTED UNIT COULD OPERATE

3. POST-PLANNING PERIOD
   - OPERATE PLANTS PAST LAST YEAR
   - REDUCE SALVAGE VALUE

THE EXPANSION PROBLEM IS TO DETERMINE THE VECTOR, $K_t$ , OF ALL GENERATING UNITS OPERATING IN YEAR $t$

$$K_t = K_{t-1} + A_t - R_t + G_t$$

$A_t$ = COMMITTED ADDITIONS

$R_t$ = COMMITTED RETIREMENTS

$G_t$ = GENERATING UNITS ADDED IN YEAR FROM LIST OF CANDIDATE PLANTS

THE OBJECTIVE FUNCTION IS TO FIND THE MINIMUM

$B_j$ AMONG ALL $j$

$$B_j = \sum_{t=1}^{t=T} \left( \bar{I}_{j,t} - \bar{S}_{j,t} + \bar{F}_{j,t} + \bar{M}_{j,t} + \bar{U}_{j,t} \right)$$

t = TIME

T = STUDY PERIOD END

I = CAPITAL COSTS

S = SALVAGE VALUE

F = FUEL COSTS

M = O & M COSTS

U = UNSERVED ENERGY COSTS

COSTS ARE DISCOUNTED AT RATE $i$

RELIABILITY CONSTRAINTS MUST BE MET
FOR A CONFIGURATION TO BE ALLOWED

$$(1 + a_t)\, D_t \geq P(K_t) \geq (1 + b_t)\, D_t$$

$$\text{LOLP}\ (K_t) \leq C_t$$

WHERE

$a_t$ = MAXIMUM RESERVE MARGIN

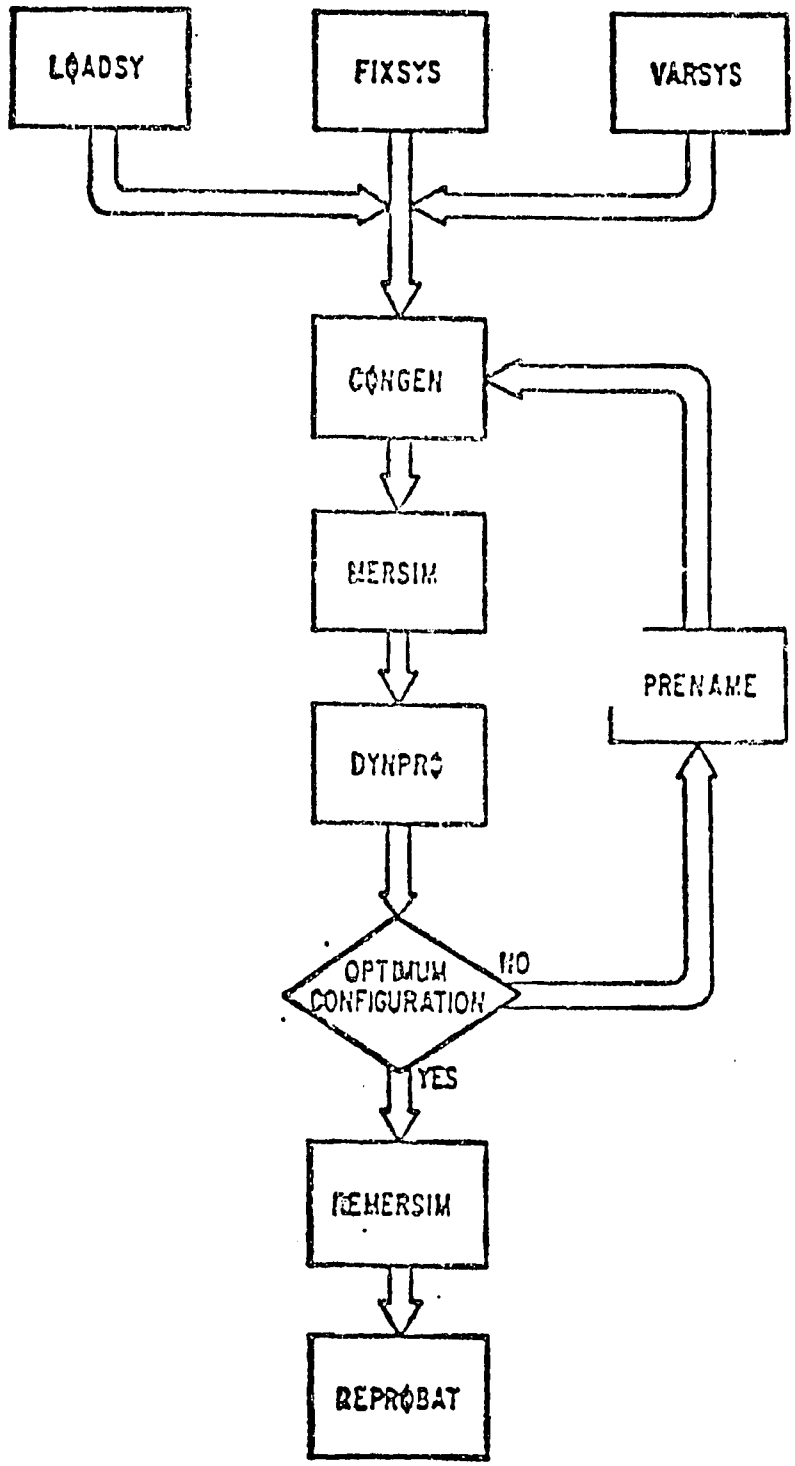
$b_t$ = MINIMUM RESERVE MARGIN

$C_t$ = CRITICAL LOLP

$D_t$ = PEAK DEMAND (IN CRITICAL PERIOD)

$P(K_t)$ = INSTALLED CAPACITY IN YEAR $t$

WASP IS ORGANIZED INTO SEVERAL SPECIFIC PROCEDURES



## KEY INPUT TO WASP INCLUDES:

- DEMAND AND LOAD DURATION DATA (SEASONAL)
- HYDROLOGICAL VARIATIONS (SEASONAL)
- UNIT SIZE, FORCED OUTAGE, SCHEDULED MAINTENANCE OF CANDIDATE UNITS
- EXISTING SYSTEM AND COMMITMENTS
- ECONOMIC PARAMETERS
- RELIABILITY CONSTRAINTS

## KEY OUTPUT FROM WASP INCLUDES:

- OPTIMUM EXPANSION PLAN OVER STUDY PERIOD
- EXPECTED GENERATION FROM ALL UNITS FOR ALL PERIODS
- RELIABILITY PERFORMANCE (LOLP, UNSERVED ENERGY, RESERVE MARGINS)
- FOREIGN AND DOMESTIC EXPENDITURES
- CASH FLOW OVER TIME
- SENSITIVITY TO KEY PARAMETERS

CALCULATIONS ARE PERFORMED FOR UP TO FIVE HYDROLOGICAL CONDITIONS

$$\bar{F}_{j,t} = (1 + i)^{-t-0.5} \sum_{h} \alpha_h \quad C_{j,t,h}$$

$\alpha_h$ = PROBABILITY OF HYDROLOGICAL CONDITION h

$C_{j,t,h}$ = FUEL PLUS VARIABLE O & M COST FOR ALL PLANTS IN HYDRO CONDITION h

FIXED COSTS ARE INDEPENDENT OF THE HYDROLOGICAL CONDITIONS FOR A PARTICULAR YEAR

$$\bar{I}_{j,t} = (1 + i)^{-t} \sum_{\ell} \text{UNIT CAPITAL COSTS}$$

$$\bar{S}_{j,t} = (1 + i)^{-T} \; V_{j,t} \; I_{j,t}$$

$$\bar{M}_{j,t} = (1 + i)^{-t-0.5} \sum_{k} \text{UNIT FIXED COSTS}$$

WHERE

$i$ = DISCOUNT RATE

$\ell$ = UNITS ADDED IN YEAR $t$

$V_{j,t}$ = SALVAGE VALUE FACTOR

$\bar{M}_{j,t}$ = DISCOUNTED FIXED O&M COSTS FOR CONFIGURATION $j$ IN YEAR $t$

$k$ = ALL UNITS IN THE OPERATING SYSTEM

THE DIMENSIONS OF THE WASP-III
PROGRAM ARE LARGE

UP TO 30 YEARS STUDY PERIOD

UP TO 12 PERIODS PER YEAR

SEVEN FUEL TYPES; 5 THERMAL, 2 HYDRO

UP TO 58 THERMAL PLANTS OF
MULTIPLE UNITS EACH

TWO HYDROELECTRIC PLANT TYPES OF
ANY NUMBER OF PROJECTS IN FIXSYS AND
UP TO 30 PROJECTS IN SEQUENCE IN VARSYS

UP TO 300 CONFIGURATIONS IN ANY YEAR

UP TO 3000 SYSTEM CONFIGURATIONS FOR
DYNAMIC OPTIMIZATION

UP TO 14 CANDIDATE PLANT TYPES IN VARSYS

THE MODEL FOR THERMAL AND NUCLEAR POWER PLANTS IS STRAIGHTFORWARD

- MWB: MINIMUM CAPACITY
- MWC: MAXIMUM CAPACITY
- SPIN: SPINNING RESERVE CAPACITY
- BASE HEAT RATE
- AVERAGE INCREMENTAL HEAT RATE
- MAINT: MAINTENANCE REQUIREMENT
- FOR: FORCED OUTAGE RATE
- CAPITAL INVESTMENT COST
- VARIABLE FUEL COST
- FIXED OPERATING COST
- FUEL INVENTORY COST

## WASP-III HAS TWO BASIC TYPES OF HYDROELECTRIC PLANTS

- RUN-OF-RIVER PLANTS
- PEAKING PLANTS
  - DAILY DUTY
  - WEEKLY DUTY
  - SEASONAL DUTY

HYDROELECTRIC PROJECTS ARE MODELED AS CONSISTING OF A BASE AND PEAK COMPONENT

$E$ : ANNUAL GENERATION

$E_k$: PERIOD GENERATION

- $E_k = \alpha_k \cdot E$

MWB: RUN-OF-RIVER CAPACITY

$MWB_k$: PERIOD RUN-OF-RIVER CAPACITY

- $MWB_k = \beta_k \cdot MWB$

MWC: TOTAL CAPACITY

$MWC_k$: PERIOD CAPACITY

- $MWC_k = \alpha_k \cdot MWC$

$MWP_k = MWC_k - MWB_k$ : PERIOD PEAK CAPACITY

$E_{B,k} = h \cdot MWB_k$ : PERIOD BASE ENERGY

$E_{P,k} = E_k - E_{B,k}$: PERIOD PEAK ENERGY

THE COMPOSITE HYDROELECTRIC PLANT CONSISTS OF THE SUM OF INDIVIDUAL PROJECTS

$$E = \sum_j E_j$$

$$E_k = \sum_j E_{j,k}$$

$$MWC_k = \sum_j MWC_{j,k}$$

$$MWB_k = \sum_j MWB_{j,k}$$

$$MWP_k = MWC_k - MWB_k$$

$$E_{B,K} = h \cdot MWB_k$$

$$E_{Pk} = E_k - E_{Bk}$$

<u>HYDROLOGICAL CONDITIONS</u>

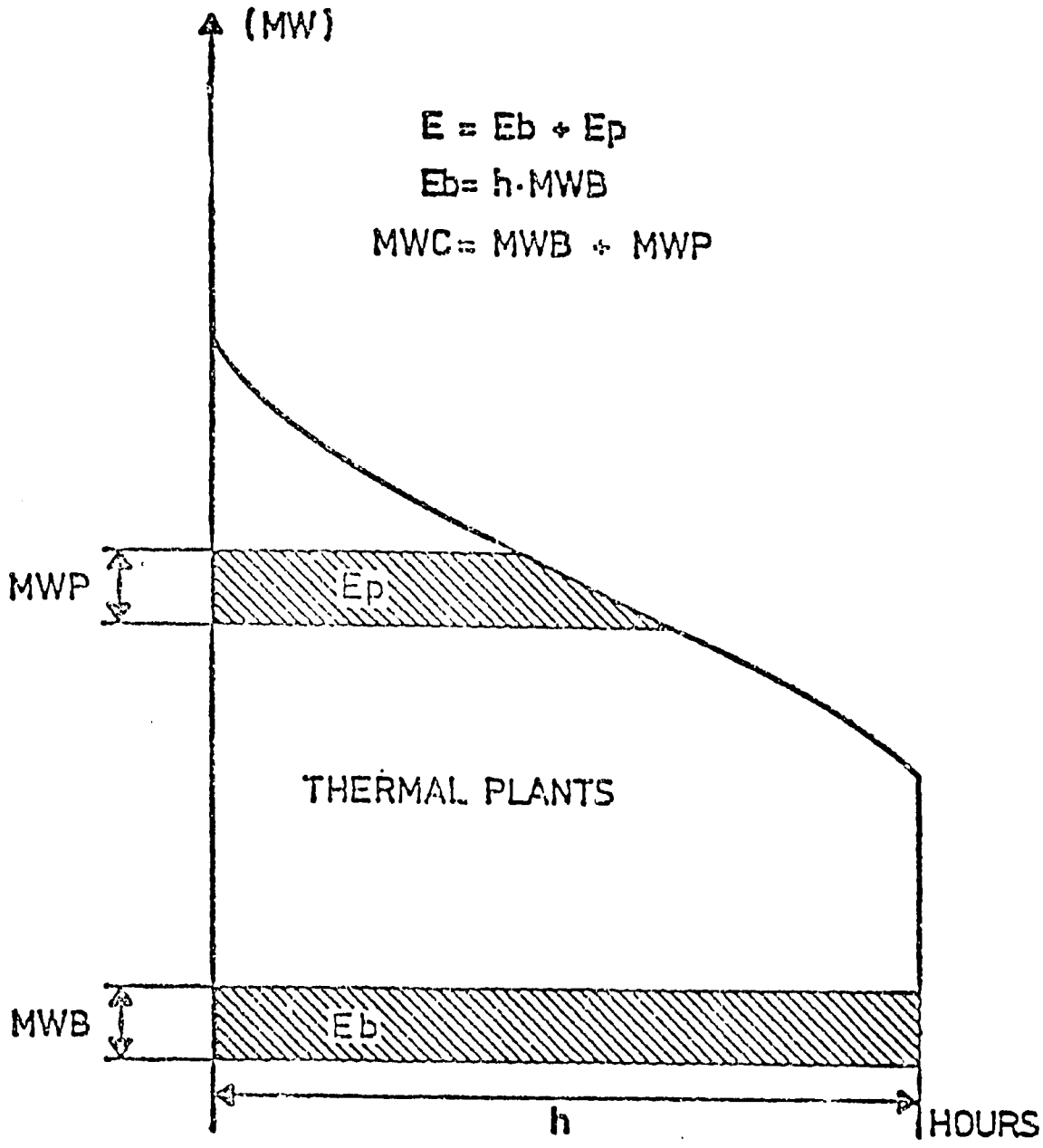
PROBABILITIES $p_i$ ; $\sum_{i=1}^{i=5} p_i = I$

ENERGY FACTOR: $a_i$

BASE CAPACITY FACTOR: $b_i$

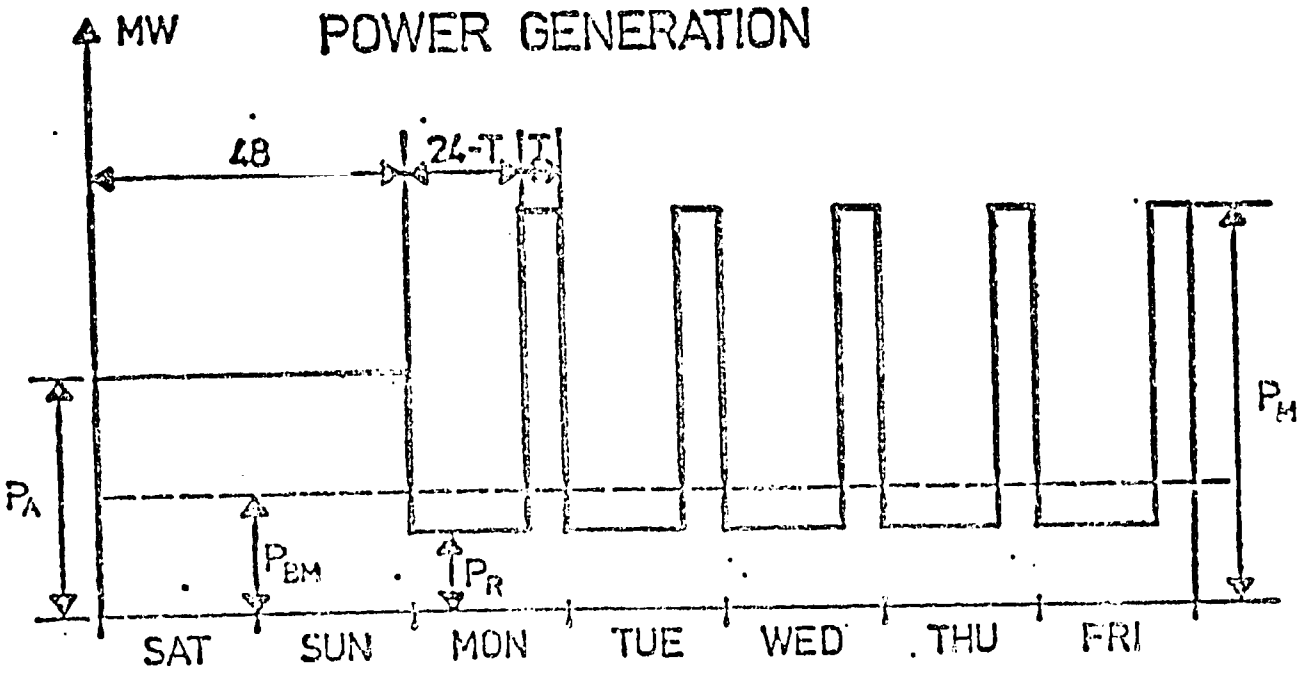
TOTAL CAPACITY FACTOR: $c_i$

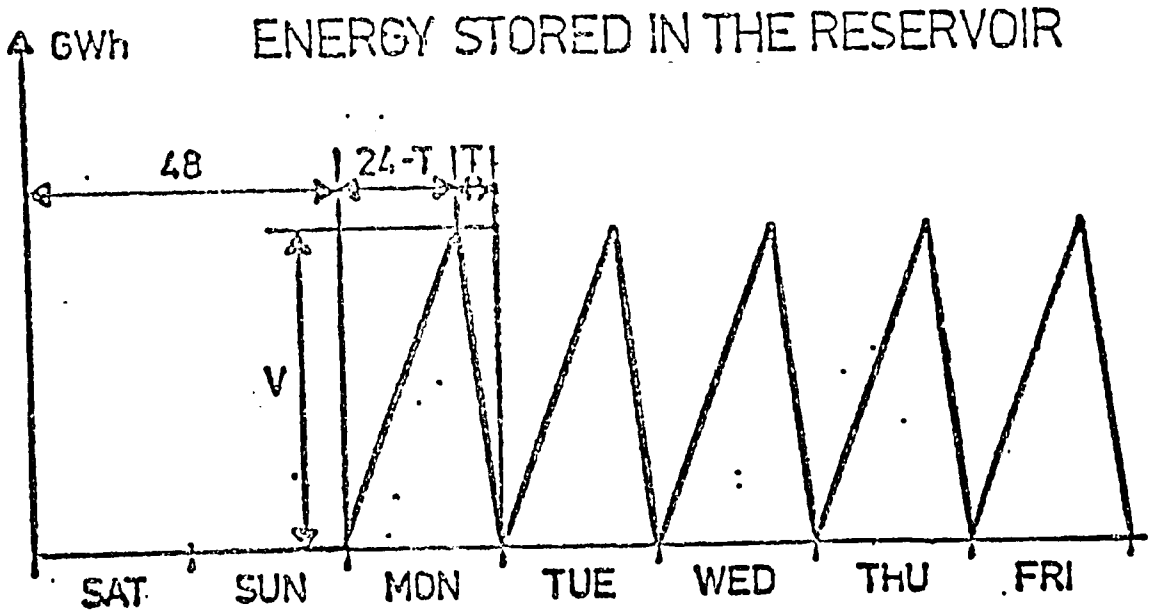
THE COMPOSITE HYDROELECTRIC PLANT FITS IN TWO PLACES ON THE LOAD DURATION CURVE




MWB: RUN-OF-RIVER CAPACITY

MWP: PEAKING CAPACITY



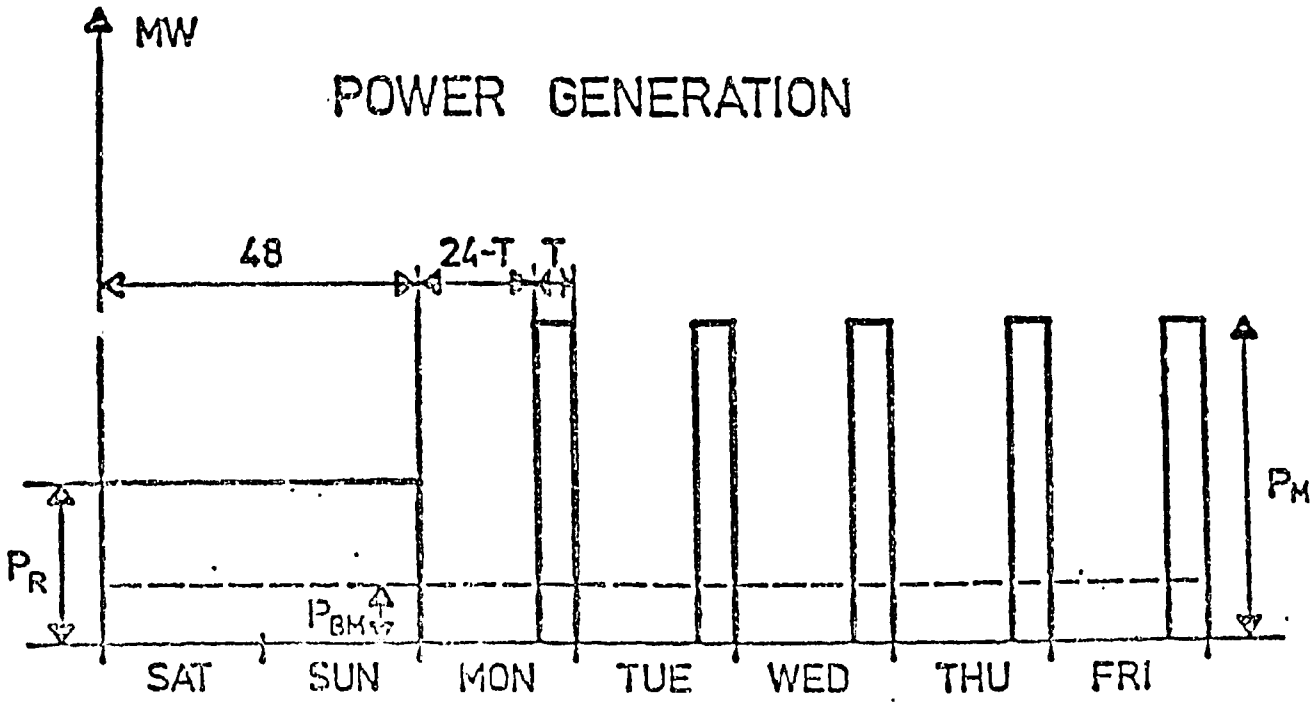



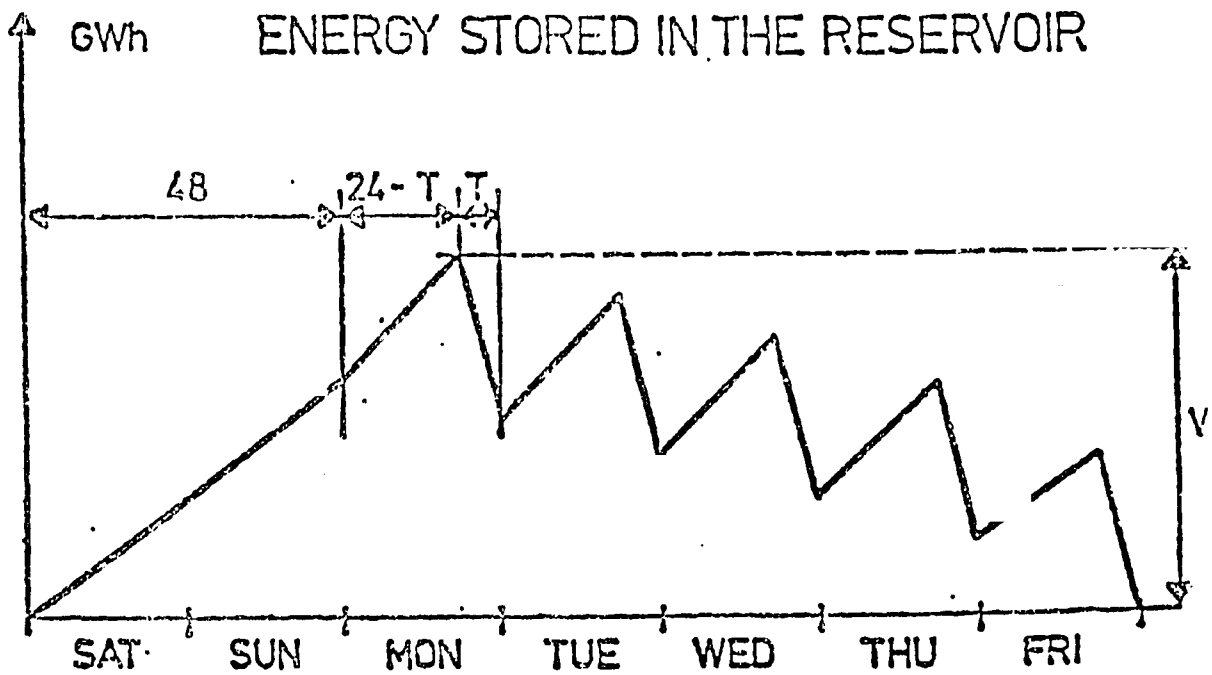

AJC
1978

SCHEME 1.

DAILY PEAKING PLANT

27




AJC
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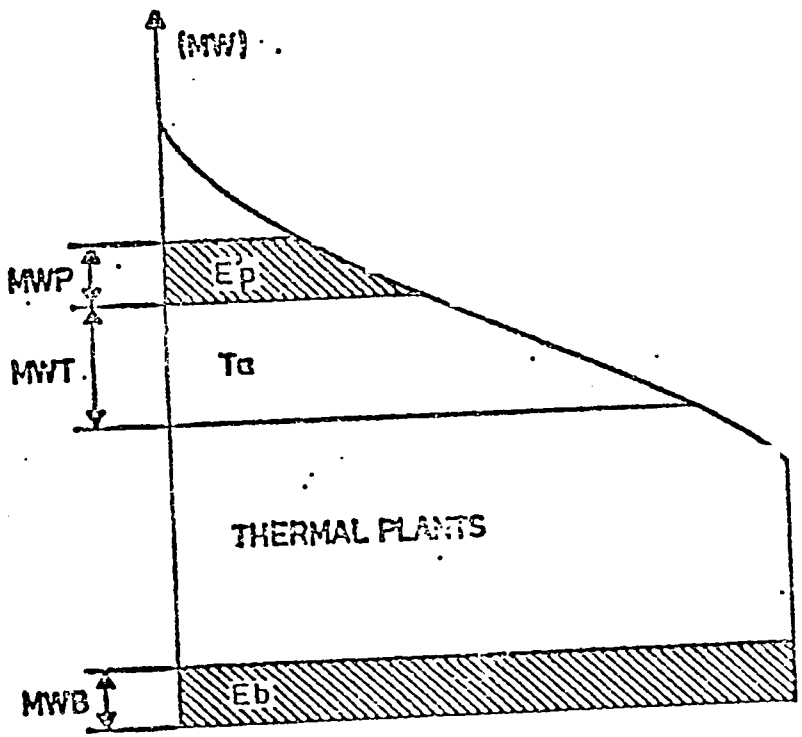
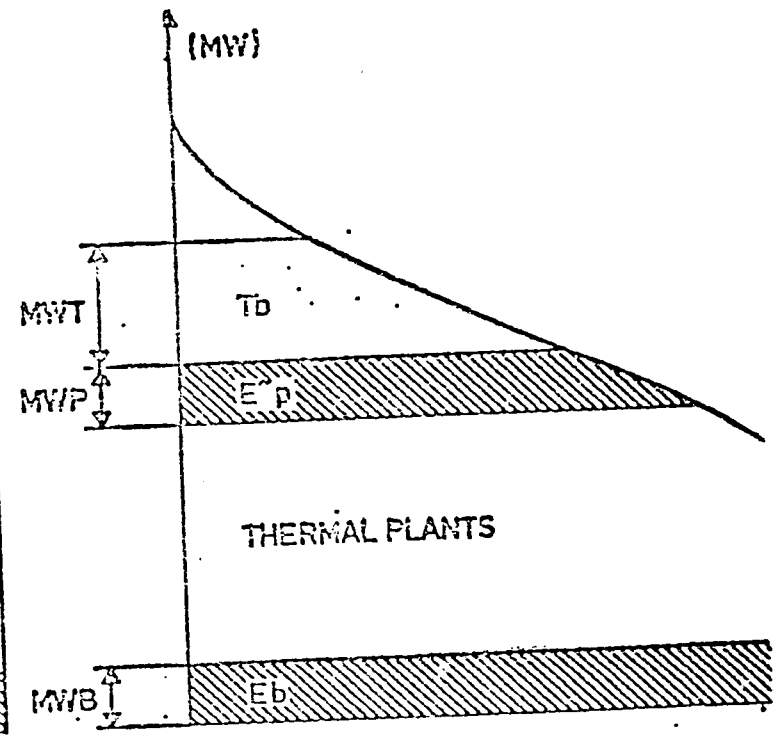
SCHEME 2

WEEKLY PEAKING PLANT

THE THERMAL UNIT ADJACENT TO THE PEAKING HYDRO
IN THE LOADING ORDER MUST BE TREATED EXPLICITLY




VALID DURING TIME FRACTION τ




VALID DURING TIME FRACTION (1-τ).

$$Eb = h \cdot MWB$$
$$Ep = E - Eb$$
$$\tau = \frac{Ep - E''p}{E'p - E''p}$$
$$T = \tau \cdot Ta + (1-\tau) \cdot Tb$$

THE WASP MODEL IS USEFUL FOR PRELIMINARY LONG-TERM PLANNING OF ELECTRICAL GENERATION SYSTEMS

- DETERMINES MINIMUM COST EXPANSION PATTERN SUBJECT TO RELIABILITY CONSTRAINTS

- DETERMINES SENSITIVITY OF RESULTS TO VARIATIONS IN KEY TECHNICAL AND ECONOMICAL PARAMETERS

# SCREENING CURVES

SCREENING CURVES PROVIDE A SIMPLIFIED APPROACH FOR QUICK ANALYSIS OF ECONOMIC COMPETITIVENESS

- SEPARATE TECHNOLOGY COSTS INTO "FIXED" AND "VARIABLE" COSTS
- CONSTRUCT COST CURVES FOR EACH TECHNOLOGY
- PLOT COST ($/KW-YR) VS. CAPACITY FACTOR
- DETERMINE LEAST COST ALTERNATIVES AS A FUNCTION OF UTILIZATION
- NUMEROUS LIMITATIONS
- NOT A SUBSTITUTE FOR THOROUGH ANALYSIS

| ANNUALIZED FIXED COSTS | = | TOTAL CAPITAL COST | X | LEVELIZED ANNUAL FIXED CHARGE RATE | + | FIXED O & M COST |
|---|---|---|---|---|---|---|
| $\left(\frac{\$}{\text{KW-YR}}\right)$ | | (\$/KWE) | | (FRACTION) | | (\$/KW-YR) |

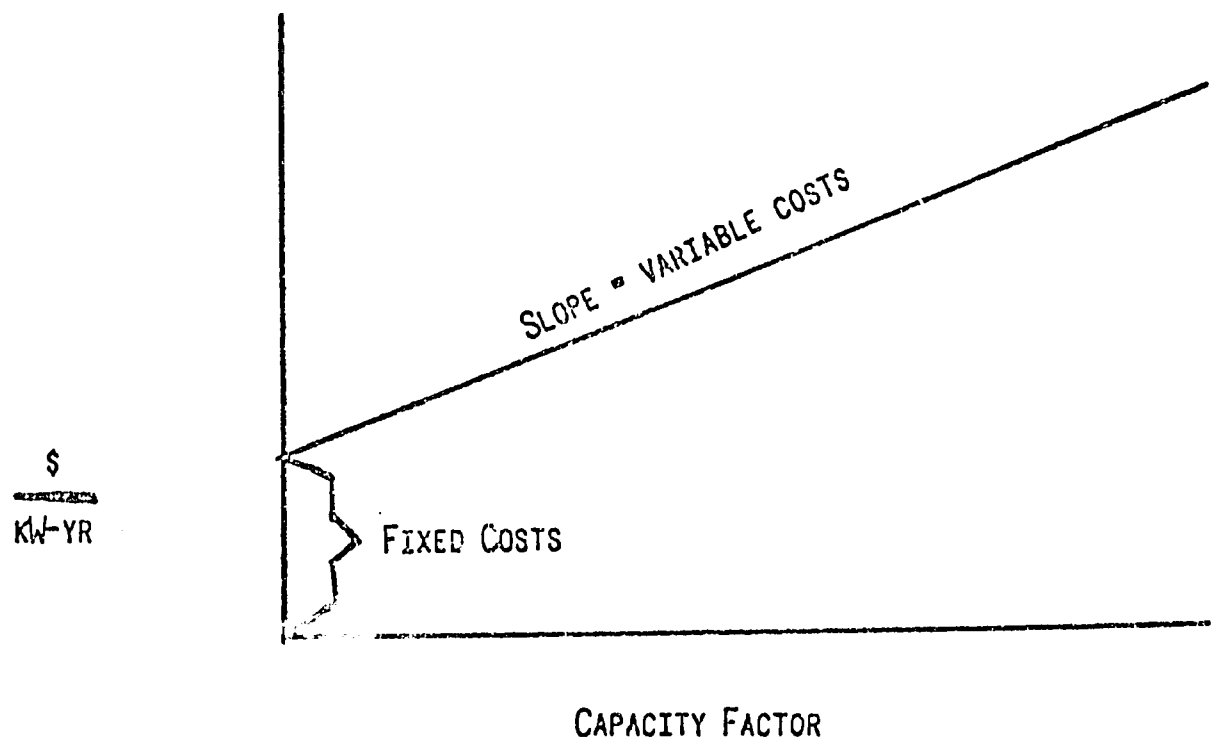
$$\text{LEVELIZED ANNUAL FIXED CHARGE RATE} = \text{CAPITAL RECOVERY FACTOR} = \frac{R\,(1+R)^{N}}{(1+R)^{N}-1}$$

$$\text{VARIABLE COST} = \text{ANNUAL AVERAGE HEAT RATE} \times \text{FUEL COST} + \text{VARIABLE O \& M COST}$$

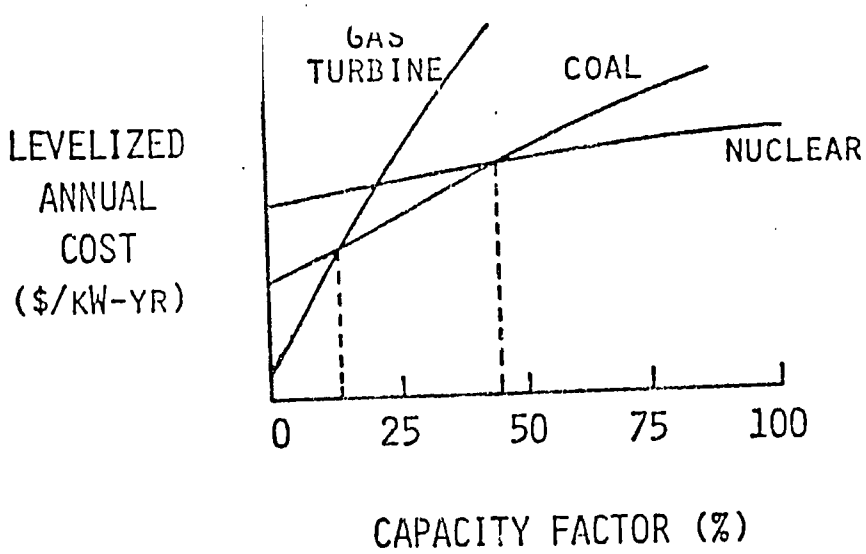
$$\left(\frac{\$}{\text{KWH}}\right) \qquad (\text{KCAL/KWH}) \qquad \left(\frac{\$}{\text{KCAL}}\right) \qquad (\$/\text{KWH})$$

FUEL AND OPERATION AND MAINTENANCE (O & M) COST SHOULD BE LEVELIZED IF REAL ESCALATION IS ASSUMED TO OCCUR

| TOTAL COST | = | ANNUALIZED FIXED COSTS | + | VARIABLE COST | X | CAPACITY FACTOR | X | 8760 |
|---|---|---|---|---|---|---|---|---|
| ($/KW-YR) | | ($/KW-YR) | | $\left(\frac{\$}{KWH}\right)$ | | (FRACTION) | | $\left(\frac{H}{YR}\right)$ |



SCREENING CURVES ARE USEFUL FOR FIRST APPROXIMATION OF COMPETITIVENESS



# PROBLEM SESSION

## LOAD DURATION CURVE

FOR THE FOLLOWING ANNUAL LOAD DURATION CURVE, COMPUTE THE TOTAL ELECTRICITY DEMAND (KWH) AND THE LOAD FACTOR:

| LOAD (MWE) | FRACTION OF TIME LOAD EXCEEDS GIVEN DEMAND |
|---|---|
| 0 | 1.0 |
| 100 | 1.0 |
| 200 | 1.0 |
| 300 | 1.0 |
| 400 (MINIMUM LOAD) | 1.0 |
| 500 | 0.80 |
| 600 | 0.40 |
| 700 | 0.20 |
| 800 | 0.10 |
| 900 | 0.05 |
| 1000 (PEAK LOAD) | 0.00 |

The discount rate is given by the weighted cost of capital. If the capital consists only of debt, the discount rate is the interest rate. Clearly, all of these rates should be defined consistently, i.e., in the absence of inflation or at a given inflation rate.

Assume for this problem:

1. Weighted cost of capital in the absence of inflation = 5%/yr.
2. No real escalation for any costs
3. Book life for all technologies = 30 years

HYPOTHETICAL COST DATA

| Technology/Size in MW | Capital Cost ($/kWe) | Fixed O&M ($/kWyr) | Variable O&M Mills/kWh | Annual Ave Heat Rate (kcal/kwh) | Fuel Cost ($/$10^6$kcal) |
|---|---|---|---|---|---|
| Coal with FGD/600 | 1140 | 16.40 | 4 | 2560 | 8 |
| Coal No FGD/200 | 1450 | 11.40 | 1 | 2590 | 8 |
| Oil/300 | 990 | 2.6 | 2 | 2500 | 20 |
| Nuclear/900 | 1530 | 32.0 | 2 | 2700 | 5 |
| Gas Turbine/100 | 330 | 0.4 | 3 | 3530 | 24 |

a) Draw the screening curves for these generating options.

b) What are the minimum cost options and over what ranges of capacity factor?

c) For the following load duration curve, calculate the fractions of total installed capacity that the screening curves indicate is optimal. Ignore all maintenance and forced outage considerations.

y = normalized load

x = normalized time

$$y = 1 - 2.68697\,x + 11.216110\,x^2 - 23.72454\,x^3 + 21.74757\,x^4 - 7.25159\,x^5$$

## SCREENING CURVES

In the initial stages of a generation expansion study, there are often many more alternatives available than can be reasonably considered in detail. Screening curves provide a simple method for eliminating, from further consideration, those alternatives which are significantly less economic.

Screening curves are only able to provide a rough-cut analysis and are not a substitute for a detailed analysis. Unit availability, for example, may not be considered when making a screening curve analysis. As a result, it is possible that the actual relationships among technologies may be distorted when a screening curve is used. Screening curves can be useful in simplifying analyses, but their limitations should be recognized.

The levelized annual fixed charge rate, exclusive of tax considerations, for sinking fund depreciation is given by:

$$R = \frac{r\,(1+r)^n}{(1+r)^n - 1}$$

where: R = levelized annual fixed charge rate in the absence of taxes (fraction),

n = book life (years), and

r = annual discount rate (fraction).

(this formula for R is the capital recovery factor defined in Eq. 5.5 of the Guidebook).

d) What is the minimum load for the load duration curve in part c)? (Expressed as a fraction of peak.)

e) What is the load factor for the load duration curve in part c)?

f) Briefly discuss why the solution to part c) is not really the optimal mix of generation types.

ORGANIZATION FOR ENERGY PLANNING
TRAINING COURSE IN ENERGY PLANNING

# ENVIRONMENTAL IMPACTS OF ELECTRIC GENERATING TECHNOLOGIES

JUNE 3, 1985

JIM PEERENBOOM
ENERGY AND ENVIRONMENTAL SYSTEMS DIVISION
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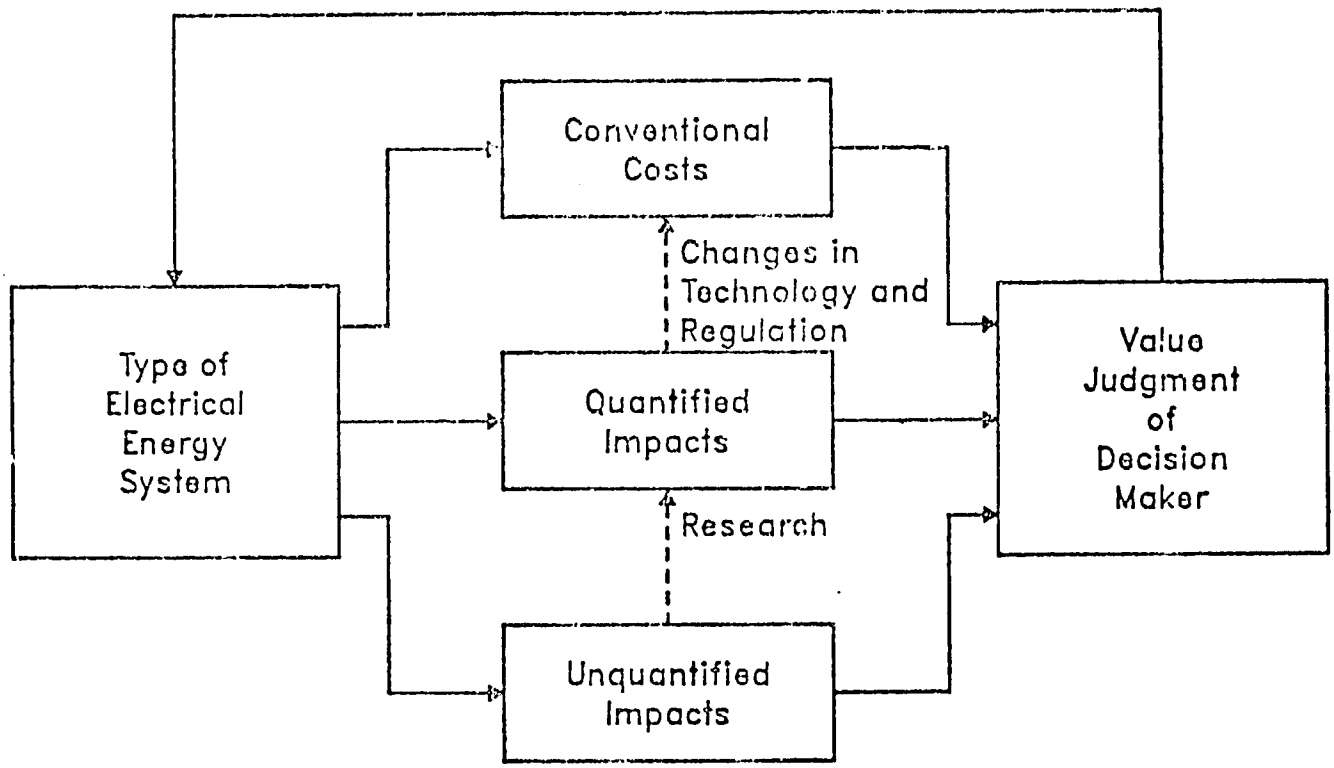
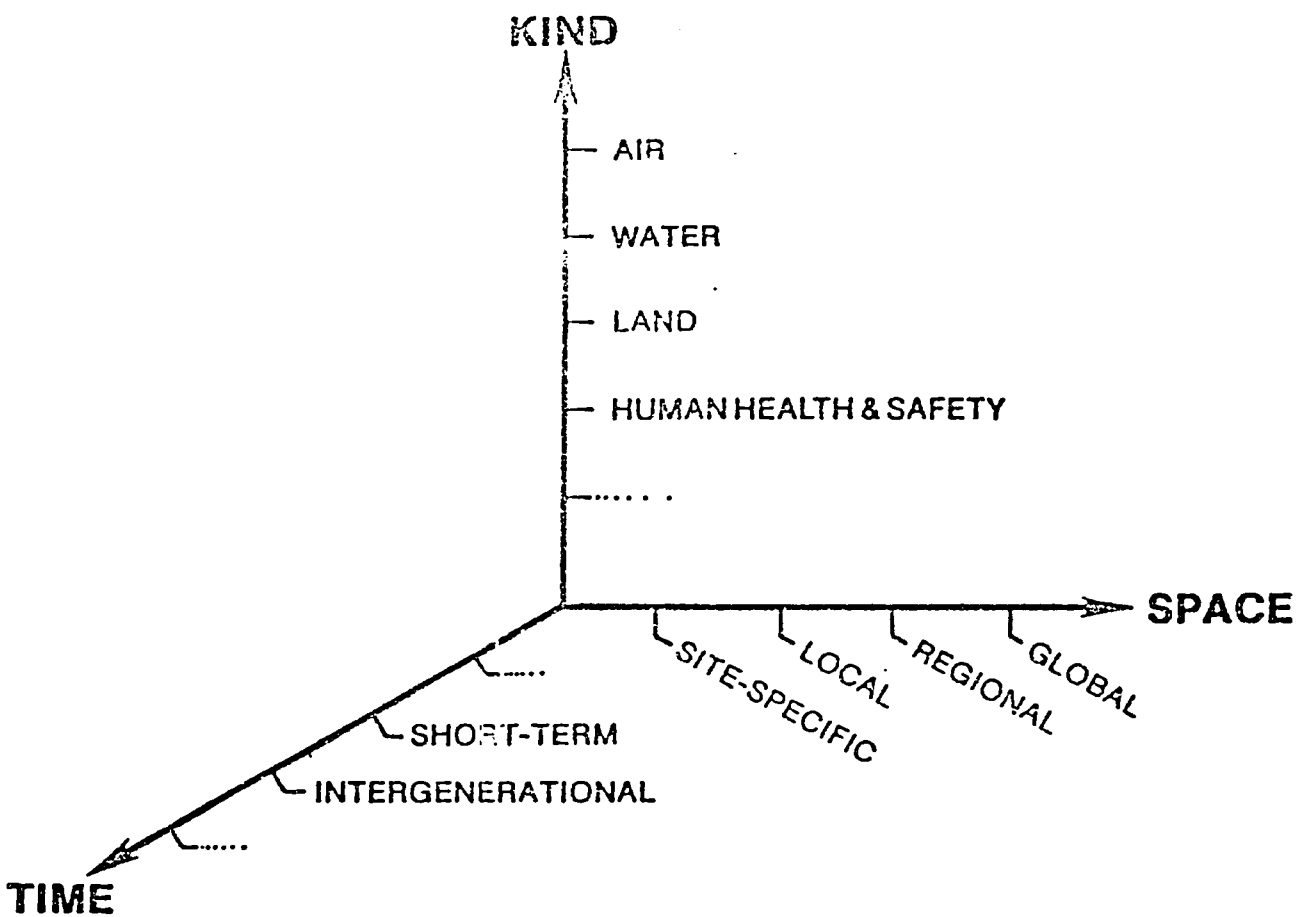
ENERGY DECISION MAKING REQUIRES THE CONSIDERATION OF BOTH ECONOMIC AND NONECONOMIC FACTORS

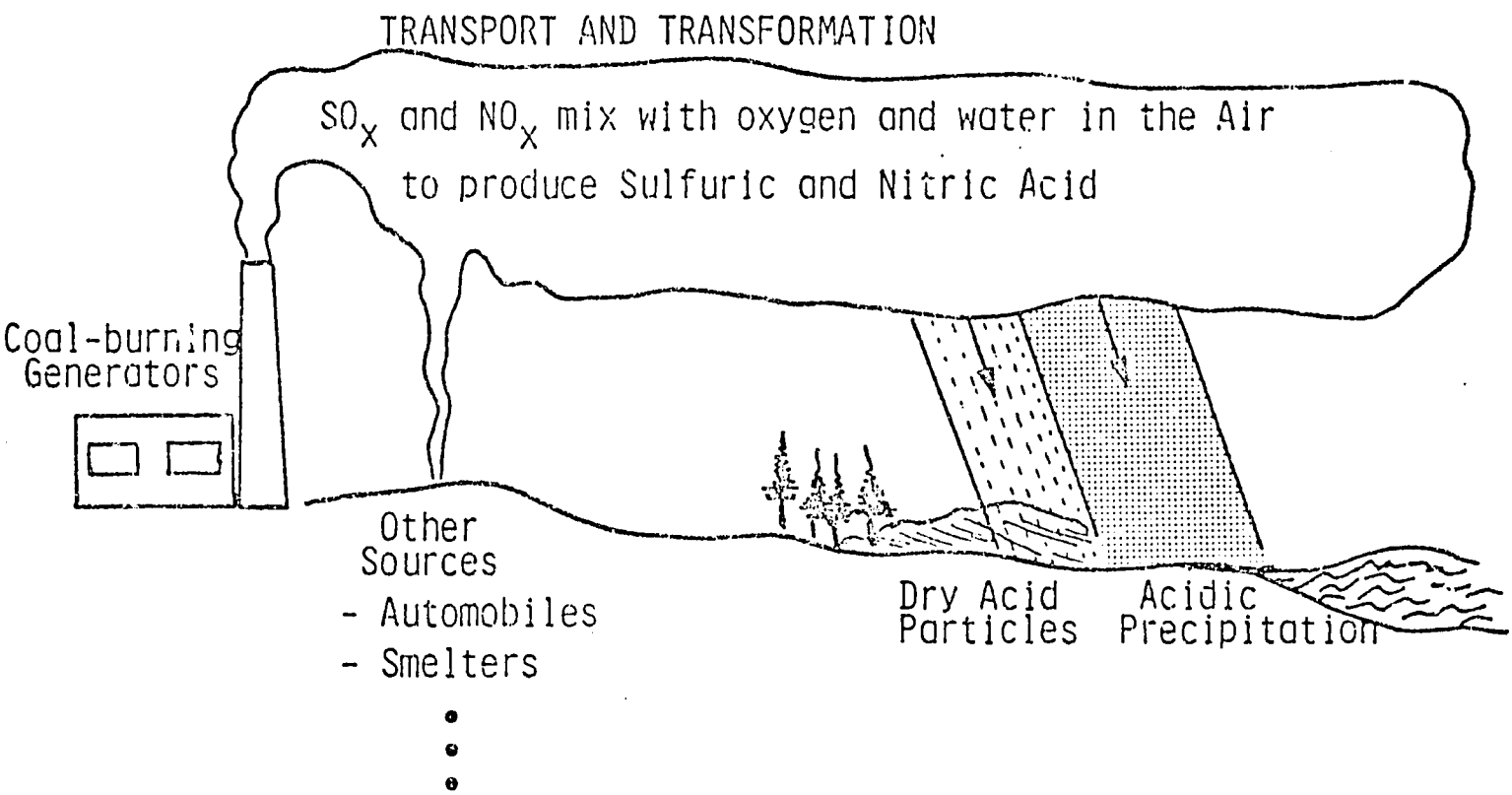


ENVIRONMENTAL IMPACTS CAN BE VIEWED FROM A MULTIDIMENSIONAL PERSPECTIVE



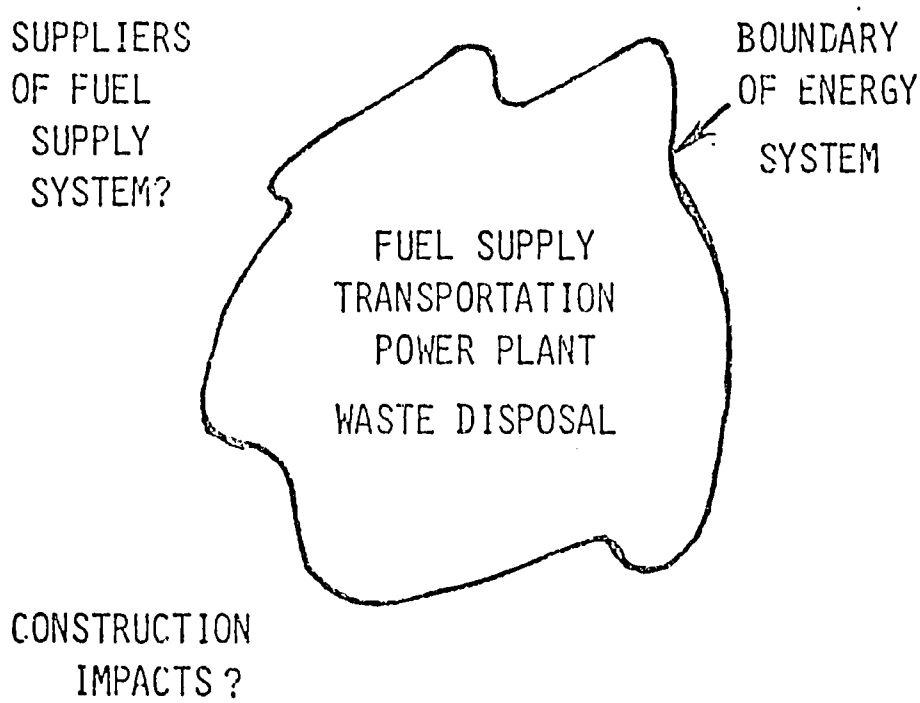
AIR EMISSIONS FROM COAL-FIRED PLANTS HAVE BEEN LINKED TO INTER-REGIONAL AND GLOBAL PROBLEMS

- ACID DEPOSITION DUE TO $SO_X$ AND $NO_X$ EMISSIONS

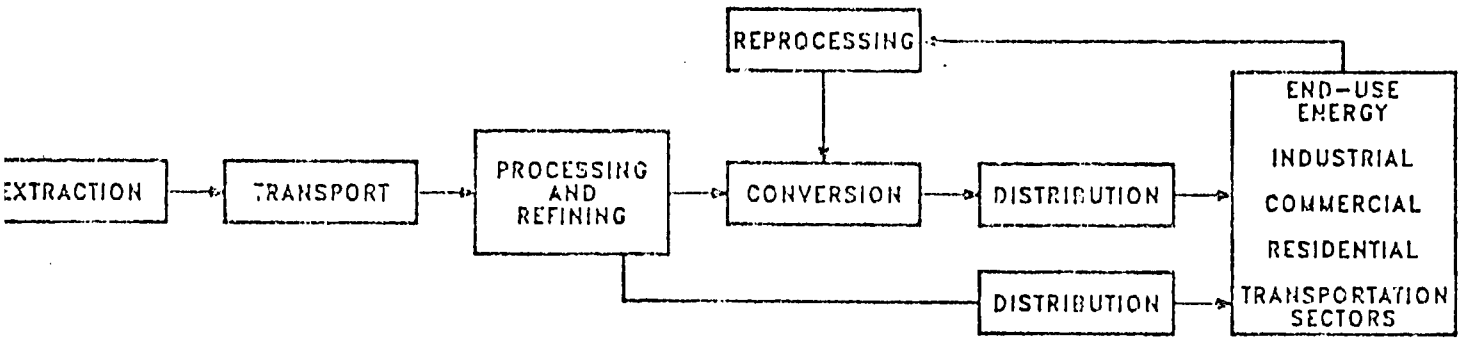



- GLOBAL CLIMATIC CHANGES DUE TO $CO_2$ EMISSIONS

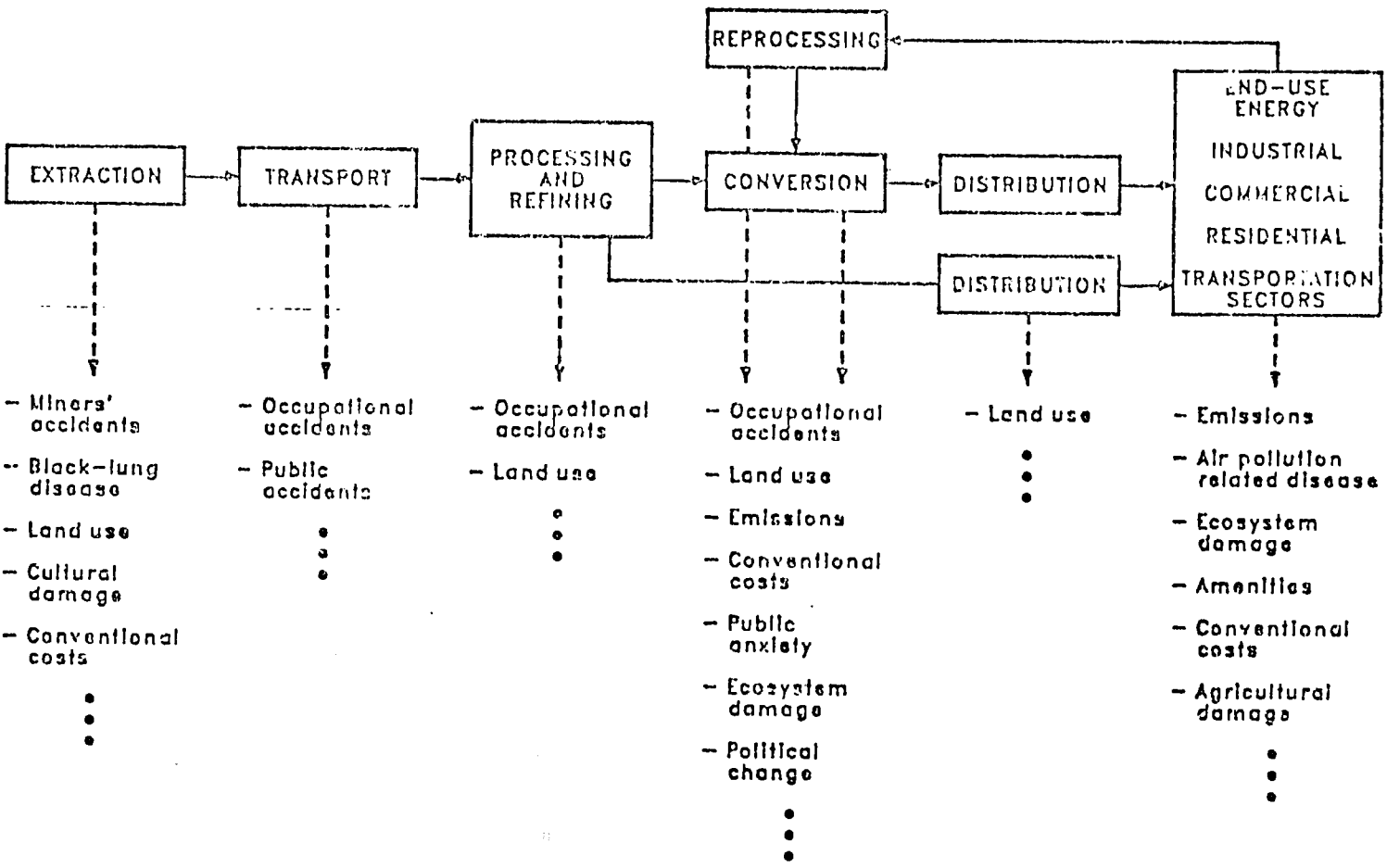
DECISIONS MUST BE MADE ON THE BOUNDARIES OF THE ENERGY SYSTEM



REFERENCE ENERGY SYSTEMS PROVIDE A CONVENIENT FRAMEWORK FOR IMPACT ANALYSIS



# IMPACTS CAN BE ASSOCIATED WITH EACH STEP IN THE REFERENCE ENERGY SYSTEM



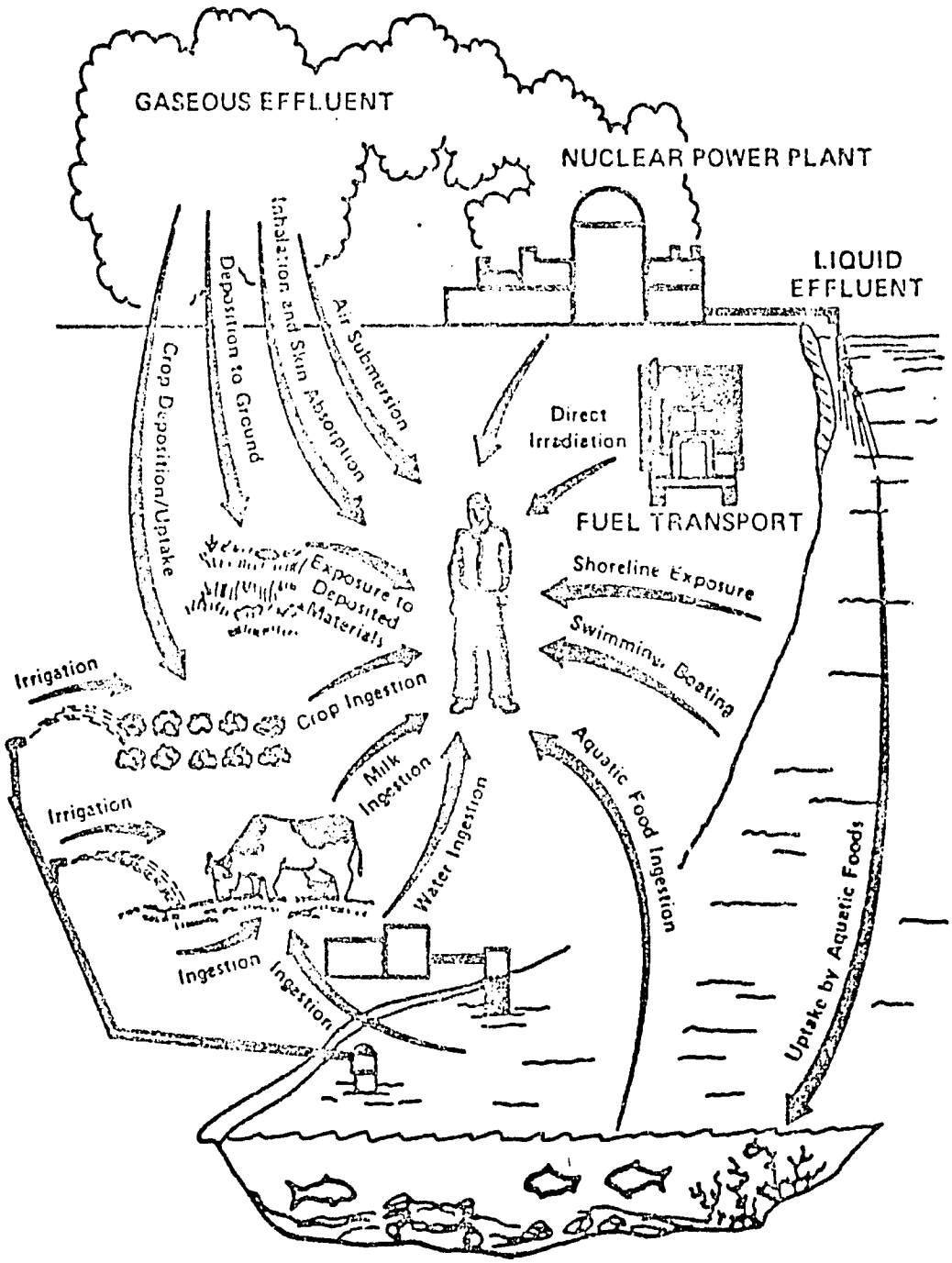
ANALYSIS OF THE ENVIRONMENTAL IMPACT OF POLLUTANTS REQUIRES THE KNOWLEDGE OF INTERRELATED CHARACTERISTICS

1. QUANTITY AND TYPES OF POLLUTANTS RELEASED;

2. DISPERSION OF THESE POLLUTANTS IN THE ENVIRONMENT;

3. ECOLOGICAL PATHWAYS FOLLOWED BY THE POLLUTANTS;

4. RELATIONSHIPS BETWEEN THE POLLUTANTS AND THE DAMAGE TO MAN AND HIS ENVIRONMENT;

5. THE EXTENT OF THE DAMAGE (INCLUDING ITS COST).

THERE ARE NUMEROUS POSSIBLE RADIATION EXPOSURE PATHWAYS TO MAN FROM NUCLEAR POWER PLANTS