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REFERENCE ENERGY SYSTEM METHODOLOGY

By

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DISCLAIMER

The United States energy system permits a wide range of substitutability among alternate energy forms because of the incorporation of many resources and conversion technologies. This system, although closely coupled to the overall economy and environment, does not contain any institution with sole planning responsibilities that encompass it. In this context, the importance of a consistent basis to examine specific sectors of the energy system is clear and it follows that a program is required which is specifically designed to provide a unified and comprehensive planning network which meets the need for consistency. The analytical techniques to be described were designed to meet this need. The Reference Energy Systems were initially developed for use in Assessment of Energy Technologies carried out by the Office of Science and Technology (OST) and were used in the development of a national R&D plan by the Chairman of the Atomic Energy Commission (AEC).[1] They were also used by the Commerce Technical Advisory Board in formulating recommendations for a National Energy Program,[2] and by ERDA in their development of an energy R&D plan.[3]

The Reference Energy System is a network representation of all of the technical activities required to supply various forms of energy to end-use activities. Technologies are defined for all operations involving specific fuels including their extraction, refinement, conversion, transport, distribution, and utilization. Each of these activities is represented by a link in the network for which efficiency, environmental impact, and cost coefficients may be specified. The network is quantified for a given year with the level of energy demands and the energy flows through the supply activities that are required to serve those demands. The total environmental effects, resource consumption, and costs for the energy system are tabulated for each planning year. Reference Energy Systems were developed for the years 1980, 1985, 1990, 2000, and 2020.

These are designed to permit the assessment of a broad set of technologies ranging from solar energy to coal and involving extraction processes as well as utilization devices. The Reference Energy Systems were formulated with minimal introduction of new technologies and were based on forecasts that were available in various sectors.

A Reference Energy System for 1972 is shown in Figure 1. This is of historical interest, but provides a starting point for the development of such systems for future years, based on anticipated growth rates in population, energy use in business and industry, and assuming moderate conservation effects caused by some technological efficiency increases in end use devices, such as autos, and demand curtailment resulting from higher energy prices.

The Reference Energy Systems are used in an assessment to evaluate new technologies by the technique of perturbation analysis. A new technology to be evaluated may involve simple replacement of an individual process or may dictate an entirely new path in the energy system network. In either case, the appropriate links representing the new technology are inserted into the Reference Energy System to produce a Perturbed Energy System (PES). Technical judgments are required to specify the efficiency, cost, and environmental parameters that describe the technology and the degree that it may be implemented in the planning year to serve specific demands. Once these determinations have been made and the appropriate technology is replaced in the Reference Energy System, the procedure simply involves a recalculation of total resource consumption, cost, and environmental effects. The impact of the new technologies are evident by comparing the outputs for the Perturbed Energy System with those of the Reference Energy System. Combinations of new technologies may be introduced in a single Perturbed Energy System and policy analyses may be performed by the same technique. In

general, additional analyses must be performed to determine the implications of new policies in terms of the parameters included in the model.

Examples of the Reference Energy Systems for 1985 and 2000 are shown in Figures 2 and 3. A markedly different future for 2000 is illustrated in Figure 4, titled Future Energy System. In contrast to Figure 3, the Future Energy System contains a host of new technologies ranging from solar energy to utilization of shale oil and synthetic gases and liquids derived from coal. Should this scenario prove feasible, it is seen that the U.S. could become a petroleum exporter to a moderate degree. The point of this comparison is to demonstrate the usefulness of the Reference Energy System Format to provide a common baseline for analysis of technological and policy options.

The Brookhaven Energy System Optimization Model (BESOM) includes the same input parameters that are used in the Reference Energy System and is used for more extensive analyses where optimization is desired. The model encompasses the entire energy system and reflects the full feasible range of interfuel substitutability. It includes both electric and nonelectric energy forms and focuses on the technical, economic, and environmental characteristics of the energy conversion, delivery, and utilization devices that make up the energy system. The analytical approach, in its general form, considers n alternate supply categories, and a set of m demand categories, providing n x m possible supply-demand combinations or paths (Figure 5). The solutions obtained indicate the optimal supply-demand configuration of the energy system within the constraints on resources, demands, and environmental impacts that are specified exogenously. The model may be formulated on a regional or national level for some future planning year by specifying, along with the appropriate constraints, a cost coefficient, supply efficiency,

utilization efficiency, and set of environmental impacts for each feasible supply-demand combination. The load-duration characteristics of electrical demands are also incorporated in the model. The optimization may be performed with respect to cost, or alternatively, with respect to an environmental effect or some arbitrary combination of such effects. Other objectives and policy issues may be incorporated in the model through constraint equations.

REFERENCES

1. The Nation's Energy Future, A Report to the President of the United States. WASH 1281 (December 1973).

2. CTAB Recommendations for a National Energy Program. U.S. Department of Commerce, Technical Advisory Board (March 1975).

3. A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future. ERDA-48 (June 1975).

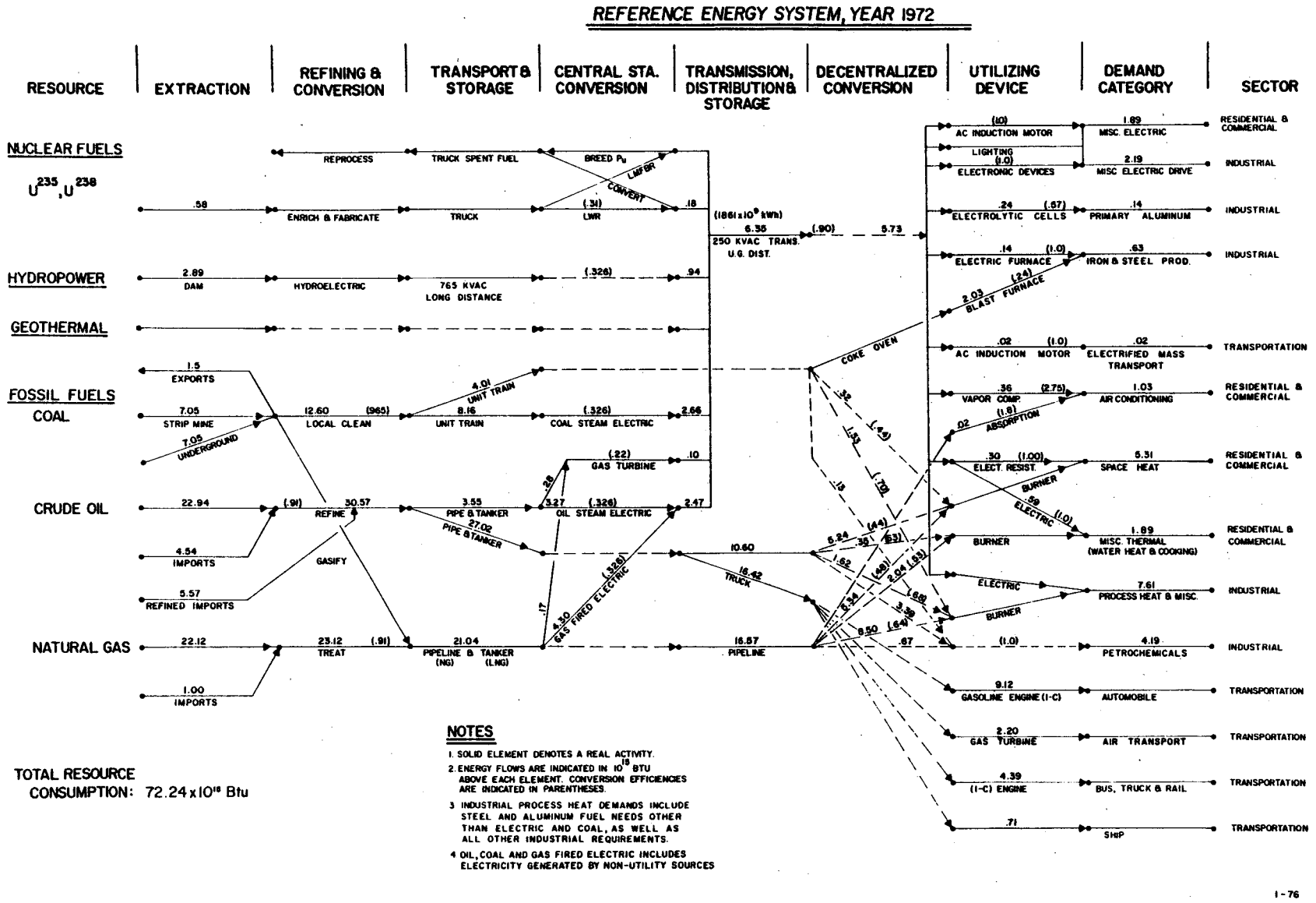

REFERENCE ENERGY SYSTEM, YEAR 1972
RESOURCE
EXTRACTION
REFINING & CONVERSION
TRANSPORT & STORAGE
CENTRAL STA. CONVERSION
TRANSMISSION, DISTRIBUTION & STORAGE
DECENTRALIZED CONVERSION
UTILIZING DEVICE
DEMAND CATEGORY
SECTOR
NUCLEAR FUELS
U235, U238
.58
ENRICH & FABRICATE
REPROCESS
TRUCK SPENT FUEL
TRUCK
BREED Pu
LMFBR
CONVERT
(.31)
LWR
.18
HYDROPOWER
2.89
DAM
HYDROELECTRIC
765 KVAC LONG DISTANCE
(.326)
.94
GEOTHERMAL
FOSSIL FUELS
COAL
1.5
EXPORTS
7.05
STRIP MINE
7.05
UNDERGROUND
12.60
(965)
LOCAL CLEAN
4.01
UNIT TRAIN
8.16
UNIT TRAIN
(.326)
COAL STEAM ELECTRIC
2.66
(.22)
GAS TURBINE
.10
CRUDE OIL
22.94
(.91)
30.57
REFINE
4.54
IMPORTS
5.57
REFINED IMPORTS
GASIFY
3.55
PIPE & TANKER
27.02
PIPE & TANKER
.28
3.27
(.326)
OIL STEAM ELECTRIC
2.47
NATURAL GAS
22.12
23.12
(.91)
TREAT
1.00
IMPORTS
21.04
PIPELINE & TANKER
(NG) (LNG)
.17
4.30
GAS FIRED ELECTRIC
(.326)
16.87
PIPELINE
(186 x 10^9 kWh)
6.35
250 KVAC TRANS.
U.G. DIST.
(.90)
5.73
10.60
16.42
TRUCK
COKE OVEN
.35
(.45)
1.55
(.70)
.15
5.24
.39
(.63)
1.62
(.48)
2.04
(.65)
.54
.68
(.64)
8.50
.67
(10)
AC INDUCTION MOTOR
LIGHTING
(1.0)
ELECTRONIC DEVICES
.24
(.67)
ELECTROLYTIC CELLS
.14
(1.0)
ELECTRIC FURNACE
(.24)
2.03
BLAST FURNACE
.02
(1.0)
AC INDUCTION MOTOR
.36
(2.75)
VAPOR COMP.
(1.8)
ABSORPTION
.02
.30
(1.00)
ELECT. RESIST.
BURNER
.59
ELECTRIC
(1.0)
BURNER
ELECTRIC
BURNER
(1.0)
1.69
MISC. ELECTRIC
2.19
MISC ELECTRIC DRIVE
.14
PRIMARY ALUMINUM
.63
IRON & STEEL PROD.
.02
ELECTRIFIED MASS TRANSPORT
1.03
AIR CONDITIONING
5.31
SPACE HEAT
1.89
MISC. THERMAL (WATER HEAT & COOKING)
7.61
PROCESS HEAT & MISC.
4.19
PETROCHEMICALS
9.12
GASOLINE ENGINE (I-C)
AUTOMOBILE
2.20
GAS TURBINE
AIR TRANSPORT
4.39
(I-C) ENGINE
BUS, TRUCK & RAIL
.71
SHIP
RESIDENTIAL & COMMERCIAL
INDUSTRIAL
INDUSTRIAL
INDUSTRIAL
TRANSPORTATION
RESIDENTIAL & COMMERCIAL
RESIDENTIAL & COMMERCIAL
RESIDENTIAL & COMMERCIAL
INDUSTRIAL
INDUSTRIAL
TRANSPORTATION
TRANSPORTATION
TRANSPORTATION
TRANSPORTATION
NOTES
1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
2. ENERGY FLOWS ARE INDICATED IN 10^15 BTU ABOVE EACH ELEMENT. CONVERSION EFFICIENCIES ARE INDICATED IN PARENTHESES.
3 INDUSTRIAL PROCESS HEAT DEMANDS INCLUDE STEEL AND ALUMINUM FUEL NEEDS OTHER THAN ELECTRIC AND COAL, AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS.
4 OIL, COAL AND GAS FIRED ELECTRIC INCLUDES ELECTRICITY GENERATED BY NON-UTILITY SOURCES
TOTAL RESOURCE CONSUMPTION: 72.24 x 10^15 Btu
1-76

Figure 1

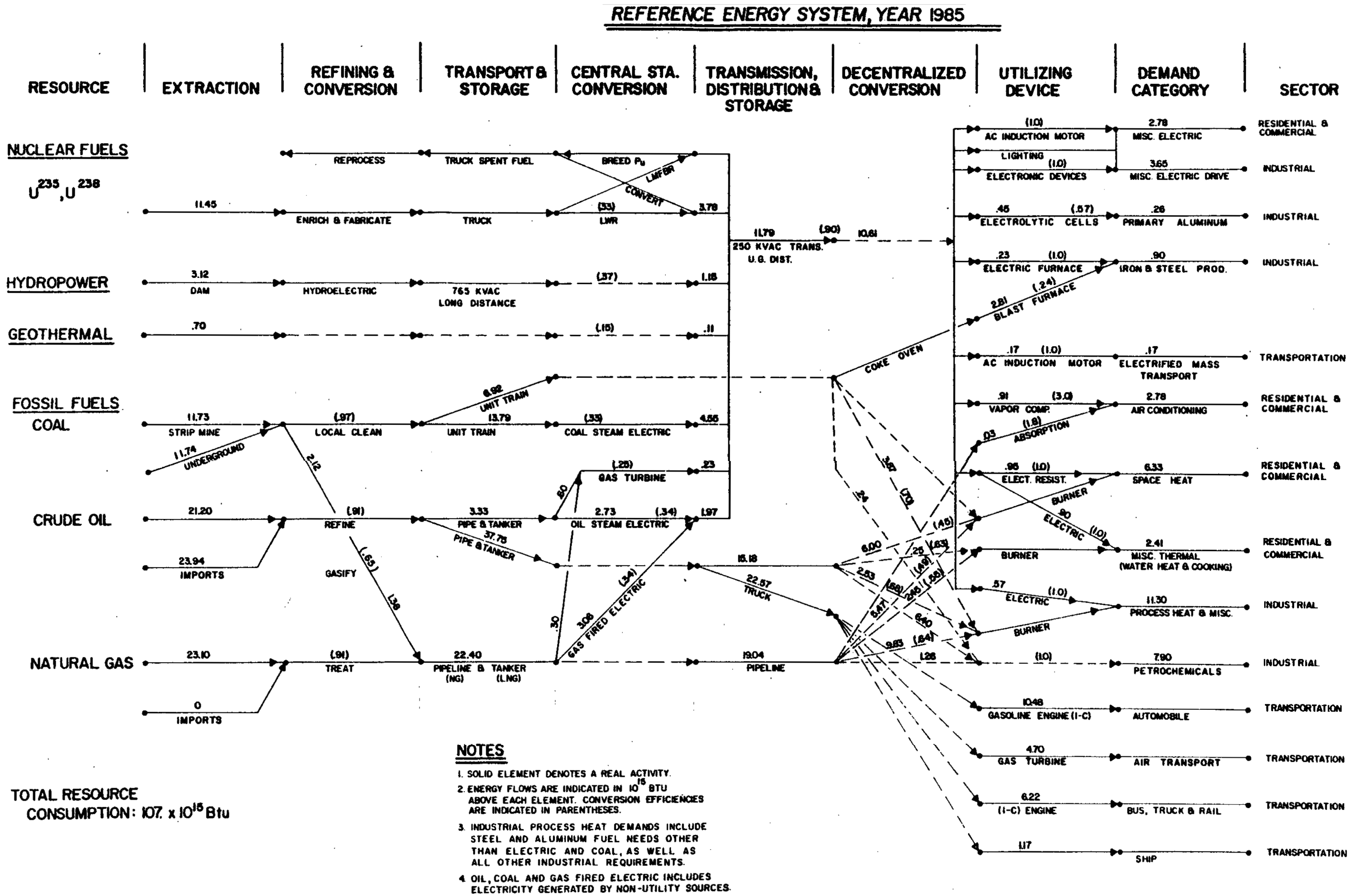

REFERENCE ENERGY SYSTEM, YEAR 1985
RESOURCE
EXTRACTION
REFINING & CONVERSION
TRANSPORT & STORAGE
CENTRAL STA. CONVERSION
TRANSMISSION, DISTRIBUTION & STORAGE
DECENTRALIZED CONVERSION
UTILIZING DEVICE
DEMAND CATEGORY
SECTOR
NUCLEAR FUELS
U235, U238
HYDROPOWER
GEOTHERMAL
FOSSIL FUELS
COAL
CRUDE OIL
NATURAL GAS
REPROCESS
TRUCK SPENT FUEL
BREED Pu
LMFBR
CONVERT
11.45
ENRICH & FABRICATE
TRUCK
(.33)
LWR
3.78
3.12
DAM
HYDROELECTRIC
765 KVAC LONG DISTANCE
(.37)
1.18
.70
(.15)
.11
6.92
UNIT TRAIN
11.73
STRIP MINE
(.97)
LOCAL CLEAN
13.79
UNIT TRAIN
(.33)
COAL STEAM ELECTRIC
4.55
11.74
UNDERGROUND
2.12
(.25)
GAS TURBINE
.23
.80
21.20
(.91)
REFINE
3.33
PIPE & TANKER
2.73
(.34)
OIL STEAM ELECTRIC
1.97
37.75
PIPE & TANKER
23.94
IMPORTS
GASIFY
(.65)
1.38
(.34)
3.06
GAS FIRED ELECTRIC
.30
23.10
(.91)
TREAT
22.40
PIPELINE & TANKER
(NG) (LNG)
0
IMPORTS
11.79
250 KVAC TRANS.
U.G. DIST.
(.90)
10.61
15.18
22.57
TRUCK
19.04
PIPELINE
COKE OVEN
(1.0)
AC INDUCTION MOTOR
LIGHTING
(1.0)
ELECTRONIC DEVICES
2.78
MISC. ELECTRIC
3.65
MISC. ELECTRIC DRIVE
.45
(.57)
ELECTROLYTIC CELLS
.26
PRIMARY ALUMINUM
.23
(1.0)
ELECTRIC FURNACE
.90
IRON & STEEL PROD.
(.24)
2.81
BLAST FURNACE
.17
(1.0)
AC INDUCTION MOTOR
.17
ELECTRIFIED MASS TRANSPORT
.91
(3.0)
VAPOR COMP.
2.78
AIR CONDITIONING
(1.6)
.03
ABSORPTION
.95
(1.0)
ELECT. RESIST.
6.33
SPACE HEAT
BURNER
.90
ELECTRIC
(1.0)
BURNER
2.41
MISC. THERMAL (WATER HEAT & COOKING)
.57
(1.0)
ELECTRIC
11.30
PROCESS HEAT & MISC.
BURNER
(1.0)
7.90
PETROCHEMICALS
10.48
GASOLINE ENGINE (I-C)
AUTOMOBILE
4.70
GAS TURBINE
AIR TRANSPORT
6.22
(I-C) ENGINE
BUS, TRUCK & RAIL
1.17
SHIP
RESIDENTIAL & COMMERCIAL
INDUSTRIAL
INDUSTRIAL
INDUSTRIAL
TRANSPORTATION
RESIDENTIAL & COMMERCIAL
RESIDENTIAL & COMMERCIAL
RESIDENTIAL & COMMERCIAL
INDUSTRIAL
INDUSTRIAL
TRANSPORTATION
TRANSPORTATION
TRANSPORTATION
TRANSPORTATION
3.57
(.70)
.24
(.45)
6.00
.25
(.63)
2.53
(.68)
(.60)
(.55)
2.46
5.47
6.40
9.83
(.64)
1.26
TOTAL RESOURCE CONSUMPTION: 107. x 10^15 Btu
NOTES
1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
2. ENERGY FLOWS ARE INDICATED IN 10^15 BTU ABOVE EACH ELEMENT. CONVERSION EFFICIENCIES ARE INDICATED IN PARENTHESES.
3. INDUSTRIAL PROCESS HEAT DEMANDS INCLUDE STEEL AND ALUMINUM FUEL NEEDS OTHER THAN ELECTRIC AND COAL, AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS.
4. OIL, COAL AND GAS FIRED ELECTRIC INCLUDES ELECTRICITY GENERATED BY NON-UTILITY SOURCES.

Figure 2

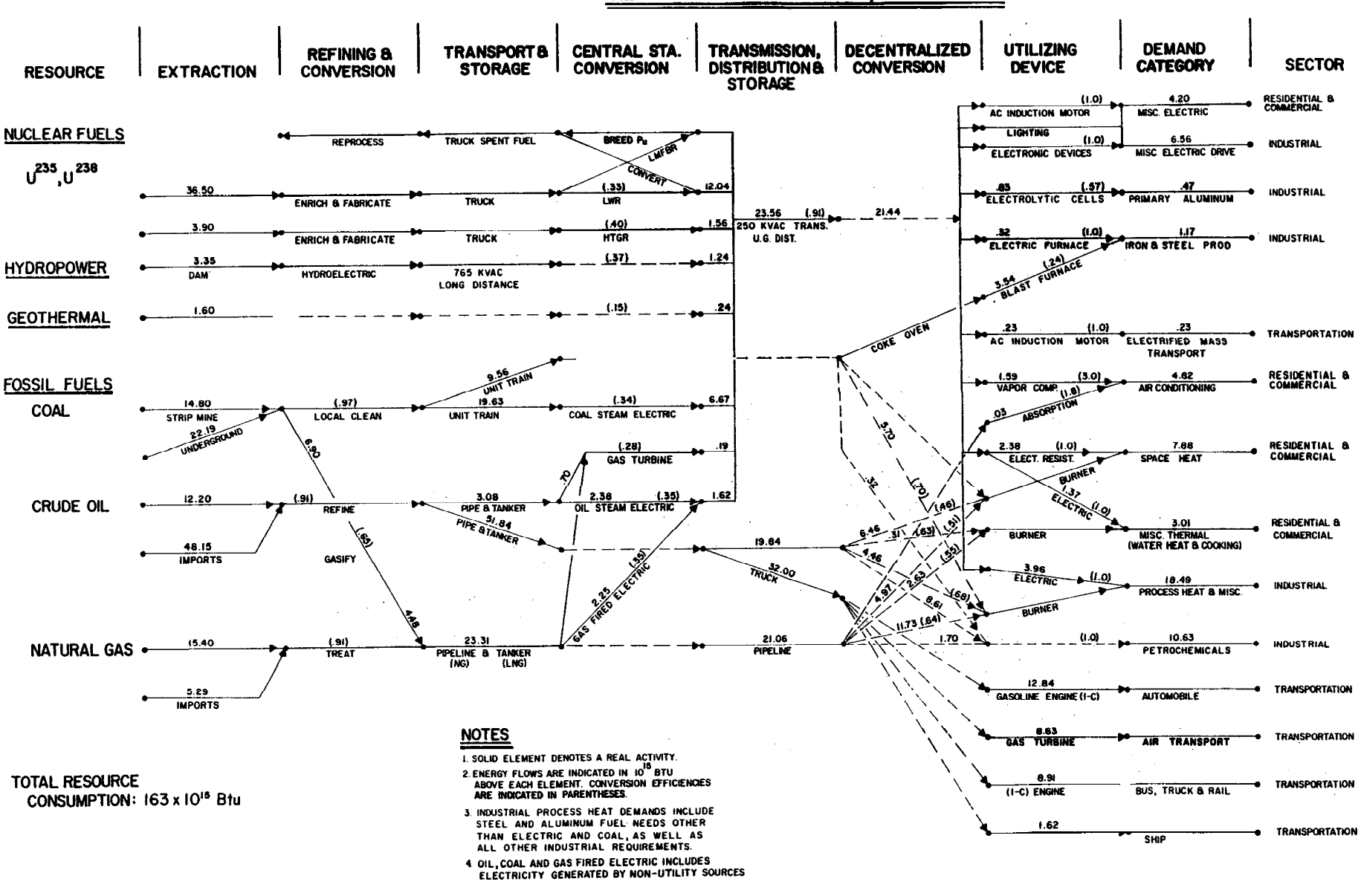

REFERENCE ENERGY SYSTEM, YEAR 2000
RESOURCE
EXTRACTION
REFINING & CONVERSION
TRANSPORT & STORAGE
CENTRAL STA. CONVERSION
TRANSMISSION, DISTRIBUTION & STORAGE
DECENTRALIZED CONVERSION
UTILIZING DEVICE
DEMAND CATEGORY
SECTOR
NUCLEAR FUELS
U235, U238
HYDROPOWER
GEOTHERMAL
FOSSIL FUELS
COAL
CRUDE OIL
NATURAL GAS
REPROCESS
TRUCK SPENT FUEL
BREED Pu
LMFBR
CONVERT
36.50
ENRICH & FABRICATE
TRUCK
(.33)
LWR
12.04
3.90
ENRICH & FABRICATE
TRUCK
(.40)
HTGR
1.56
3.35
DAM
HYDROELECTRIC
765 KVAC LONG DISTANCE
(.37)
1.24
1.60
(.15)
.24
14.80
STRIP MINE
22.19
UNDERGROUND
(.97)
LOCAL CLEAN
9.56
UNIT TRAIN
19.63
UNIT TRAIN
(.34)
COAL STEAM ELECTRIC
6.67
6.90
(.28)
GAS TURBINE
.19
.70
12.20
(.91)
REFINE
3.08
PIPE & TANKER
2.38
(.35)
OIL STEAM ELECTRIC
1.62
48.15
IMPORTS
GASIFY
(.63)
51.84
PIPE & TANKER
.44
2.25
(.35)
GAS FIRED ELECTRIC
15.40
(.91)
TREAT
23.31
PIPELINE & TANKER
(NG)
(LNG)
5.29
IMPORTS
23.56
(.91)
250 KVAC TRANS.
U.G. DIST.
21.44
19.84
TRUCK
32.00
21.06
PIPELINE
COKE OVEN
.32
5.70
1.70
(.46)
6.45
.51
(.63)
(.51)
4.46
2.63
(.55)
4.97
8.61
(.68)
11.73
(.64)
1.70
(1.0)
AC INDUCTION MOTOR
4.20
MISC. ELECTRIC
RESIDENTIAL & COMMERCIAL
LIGHTING
(1.0)
ELECTRONIC DEVICES
6.56
MISC ELECTRIC DRIVE
INDUSTRIAL
.83
(.97)
ELECTROLYTIC CELLS
.47
PRIMARY ALUMINUM
INDUSTRIAL
.32
(1.0)
ELECTRIC FURNACE
1.17
IRON & STEEL PROD
INDUSTRIAL
(.24)
3.54
BLAST FURNACE
.23
(1.0)
AC INDUCTION MOTOR
.23
ELECTRIFIED MASS TRANSPORT
TRANSPORTATION
1.59
(3.0)
VAPOR COMP.
(1.8)
4.62
AIR CONDITIONING
RESIDENTIAL & COMMERCIAL
.03
ABSORPTION
2.38
(1.0)
ELECT. RESIST.
7.88
SPACE HEAT
RESIDENTIAL & COMMERCIAL
BURNER
1.37
ELECTRIC
(1.0)
BURNER
3.01
MISC. THERMAL (WATER HEAT & COOKING)
RESIDENTIAL & COMMERCIAL
3.96
ELECTRIC
(1.0)
18.49
PROCESS HEAT & MISC.
INDUSTRIAL
BURNER
(1.0)
10.63
PETROCHEMICALS
INDUSTRIAL
12.84
GASOLINE ENGINE (I-C)
AUTOMOBILE
TRANSPORTATION
8.63
GAS TURBINE
AIR TRANSPORT
TRANSPORTATION
8.91
(I-C) ENGINE
BUS, TRUCK & RAIL
TRANSPORTATION
1.62
SHIP
TRANSPORTATION
NOTES
1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
2. ENERGY FLOWS ARE INDICATED IN 10^15 BTU ABOVE EACH ELEMENT. CONVERSION EFFICIENCIES ARE INDICATED IN PARENTHESES.
3. INDUSTRIAL PROCESS HEAT DEMANDS INCLUDE STEEL AND ALUMINUM FUEL NEEDS OTHER THAN ELECTRIC AND COAL, AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS.
4. OIL, COAL AND GAS FIRED ELECTRIC INCLUDES ELECTRICITY GENERATED BY NON-UTILITY SOURCES
TOTAL RESOURCE CONSUMPTION: 163 x 10^15 Btu

Figure 3

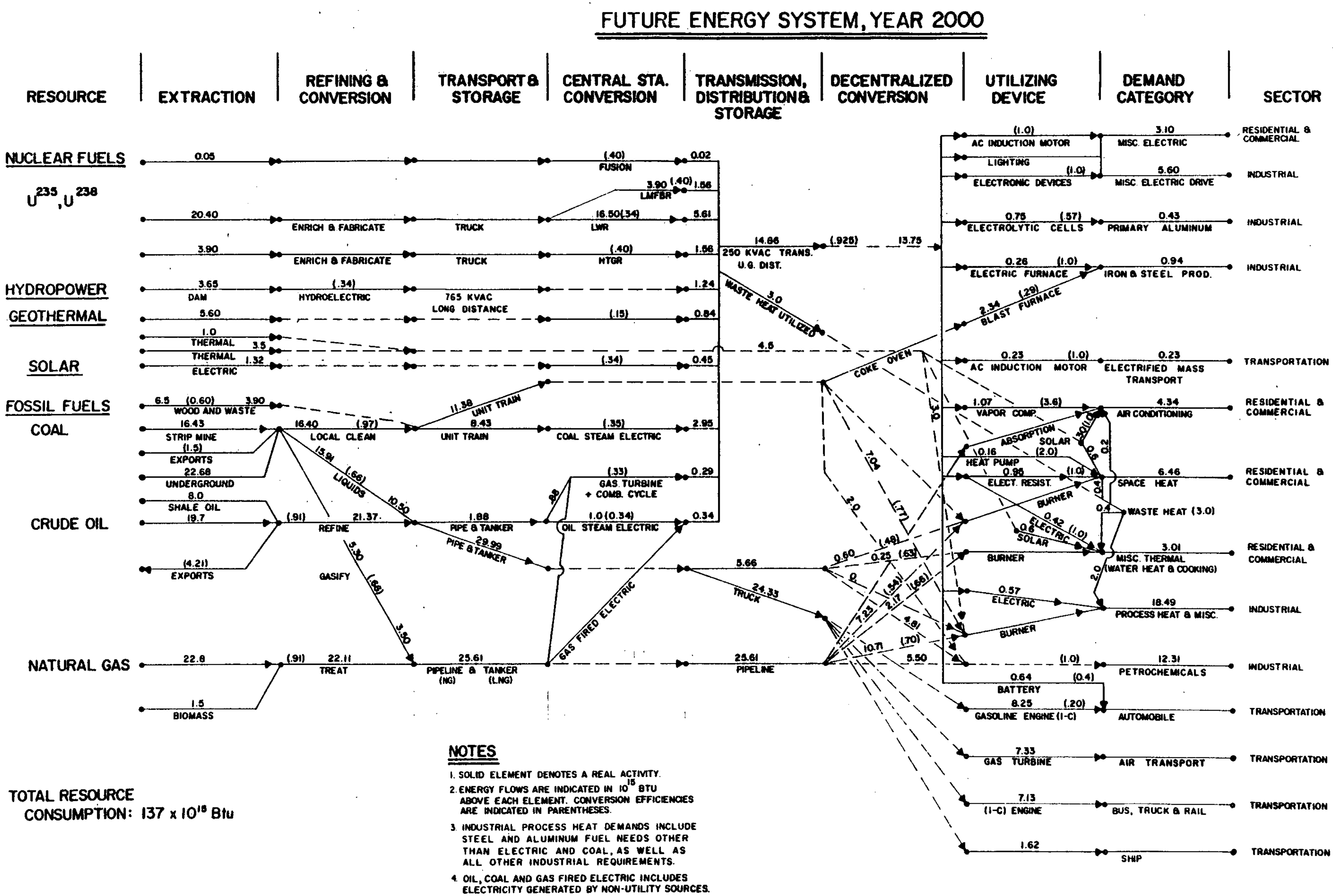
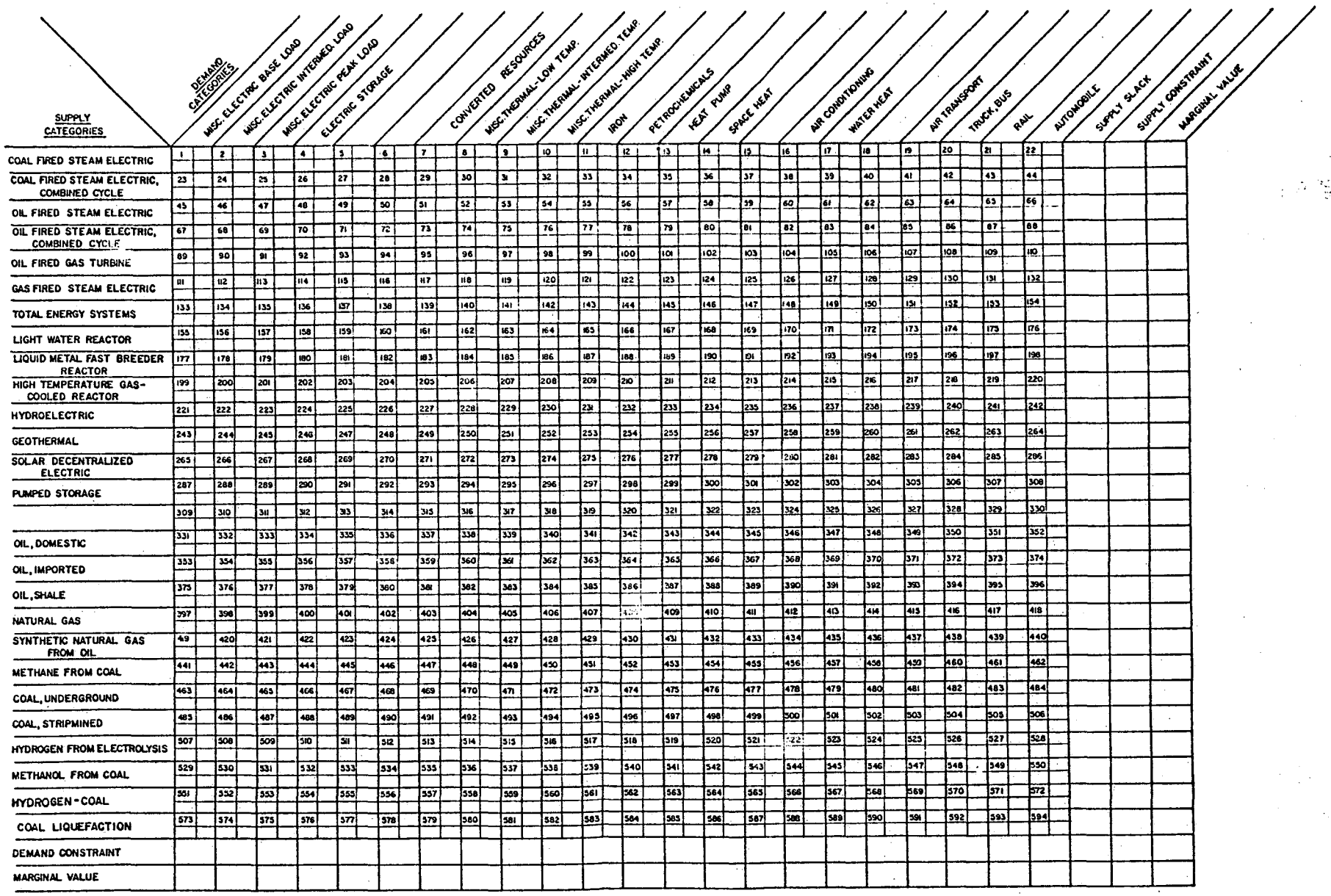

FUTURE ENERGY SYSTEM, YEAR 2000
RESOURCE
EXTRACTION
REFINING & CONVERSION
TRANSPORT & STORAGE
CENTRAL STA. CONVERSION
TRANSMISSION, DISTRIBUTION & STORAGE
DECENTRALIZED CONVERSION
UTILIZING DEVICE
DEMAND CATEGORY
SECTOR
NUCLEAR FUELS
U235, U238
HYDROPOWER
GEOTHERMAL
SOLAR
FOSSIL FUELS
COAL
CRUDE OIL
NATURAL GAS
0.05
(.40)
FUSION
0.02
3.90 (.40) 1.56
LMFBR
20.40
ENRICH & FABRICATE
TRUCK
16.50 (.34)
LWR
5.61
3.90
ENRICH & FABRICATE
TRUCK
(.40)
HTGR
1.56
3.65
DAM
(.34)
HYDROELECTRIC
765 KVAC LONG DISTANCE
1.24
5.60
(.15)
0.84
1.0
THERMAL
3.5
THERMAL
1.32
ELECTRIC
(.34)
0.45
6.5 (0.60) 3.90
WOOD AND WASTE
16.43
STRIP MINE
(1.5)
EXPORTS
22.68
UNDERGROUND
8.0
SHALE OIL
19.7
(4.21)
EXPORTS
16.40 (.97)
LOCAL CLEAN
11.38 UNIT TRAIN
8.43
UNIT TRAIN
(.35)
COAL STEAM ELECTRIC
2.95
15.91 (.66) LIQUIDS
10.50
(.91) 21.37
REFINE
1.88
PIPE & TANKER
29.99
PIPE & TANKER
(.33)
GAS TURBINE + COMB. CYCLE
0.29
1.0 (0.34)
OIL STEAM ELECTRIC
0.34
GASIFY
5.30 (.66) 3.50
22.8
(.91) 22.11
TREAT
25.61
PIPELINE & TANKER (NG) (LNG)
GAS FIRED ELECTRIC
1.5
BIOMASS
14.86
250 KVAC TRANS. U.G. DIST.
(.925)
13.75
3.0
WASTE HEAT UTILIZED
4.6
COKE OVEN
5.66
24.33
TRUCK
25.61
PIPELINE
5.50
(1.0)
AC INDUCTION MOTOR
3.10
MISC. ELECTRIC
RESIDENTIAL & COMMERCIAL
LIGHTING
(1.0)
ELECTRONIC DEVICES
5.60
MISC. ELECTRIC DRIVE
INDUSTRIAL
0.75 (.57)
ELECTROLYTIC CELLS
0.43
PRIMARY ALUMINUM
INDUSTRIAL
0.26 (1.0)
ELECTRIC FURNACE
0.94
IRON & STEEL PROD.
INDUSTRIAL
2.34 (.29) BLAST FURNACE
0.23 (1.0)
AC INDUCTION MOTOR
0.23
ELECTRIFIED MASS TRANSPORT
TRANSPORTATION
1.07 (3.6)
VAPOR COMP.
4.34
AIR CONDITIONING
RESIDENTIAL & COMMERCIAL
ABSORPTION
SOLAR
0.16 (2.0)
HEAT PUMP
0.95 (1.0)
ELECT. RESIST.
6.46
SPACE HEAT
RESIDENTIAL & COMMERCIAL
BURNER
WASTE HEAT (3.0)
0.42 (1.0)
ELECTRIC
SOLAR
BURNER
3.01
MISC. THERMAL (WATER HEAT & COOKING)
RESIDENTIAL & COMMERCIAL
0.57
ELECTRIC
18.49
PROCESS HEAT & MISC.
INDUSTRIAL
BURNER
(1.0)
12.31
PETROCHEMICALS
INDUSTRIAL
0.64 (0.4)
BATTERY
8.25 (.20)
GASOLINE ENGINE (I-C)
AUTOMOBILE
TRANSPORTATION
7.33
GAS TURBINE
AIR TRANSPORT
TRANSPORTATION
7.13
(I-C) ENGINE
BUS, TRUCK & RAIL
TRANSPORTATION
1.62
SHIP
TRANSPORTATION
NOTES
1. SOLID ELEMENT DENOTES A REAL ACTIVITY.
2. ENERGY FLOWS ARE INDICATED IN 10^15 BTU ABOVE EACH ELEMENT. CONVERSION EFFICIENCIES ARE INDICATED IN PARENTHESES.
3. INDUSTRIAL PROCESS HEAT DEMANDS INCLUDE STEEL AND ALUMINUM FUEL NEEDS OTHER THAN ELECTRIC AND COAL, AS WELL AS ALL OTHER INDUSTRIAL REQUIREMENTS.
4. OIL, COAL AND GAS FIRED ELECTRIC INCLUDES ELECTRICITY GENERATED BY NON-UTILITY SOURCES.
TOTAL RESOURCE CONSUMPTION: 137 x 10^15 Btu

Figure 4



BESOM SUPPLY/DEMAND MATRIX

6/73
8/75

Figure 5