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U.S. ENERGY FLOW CHARTS FOR 1950, 1960, 1970, 1980, 1985, AND 1990

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Abstract

Energy flow charts for the U.S., showing the origin and disposition of energy for the years 1950, 1960, 1970, 1980, 1985, and 1990, are presented along with a discussion of their development and the implications of the data they represent. An appendix describes the construction of one chart in detail, serving as an example of the method.

Introduction

In the course of U.S. energy resource and allocation studies being conducted at the Lawrence Livermore Laboratory, the U.S. energy flow charts for the years 1950, 1960, 1970, 1980, 1985, and 1990, which comprise the body of this report, were developed. In view of the widespread interest in these charts it is our purpose here to publish them together with an explanation of how they were developed and some remarks on the implications of the data which the charts are intended to organize and clarify. In our initial reports, we prepared U.S. energy distribution charts for 1970 and 1985.[1,2] The former was prepared from the preliminary data available at that time, and the latter from the Initial Appraisal Report of the National Petroleum Council (NPC).[3] Since then, we have studied additional data on past U.S. energy consumption, while the NPC[4] and the U.S. Department of the Interior (USDI)[5] have published more complete and detailed versions of their respective projections of U.S. energy consumption through 1985. Our charts for the years 1970 and earlier incorporate the more complete data included in these studies; the 1980 and 1985 projections are drawn from the NPC and USDI estimates (which differ considerably), and the 1990 chart is an extrapolation from the NPC forecast.[4] Our earlier 1985 chart, based on the NPC Initial Appraisal,[3] is included along with our new 1985 chart for comparison. An appendix describes the derivation of the values and the construction of our new chart for 1985 in considerable detail, serving as an example for the reader.

Over the last year these charts have been widely used by others in their studies of the U.S. energy situation. The recent publication "Understanding the National Energy Dilemma"[6] gives an excellent summary of the national energy problem by extending the graphic presentation of these charts to a third dimension which depicts the changes in energy end-uses over the years.

The 1950, 1960, and 1970 Energy Flow Charts

These charts were constructed from the data collected by the Bureau of Mines[5, 7] for energy supply and end-use. The data for past consumption are the best obtainable. The noted unaccounted-for losses are small, and are neglected here. Quantities have been rounded to the nearest tenth, which has led to certain inaccuracies. For example, from the 1950 chart it would appear that the efficiency of generating electricity by thermal means was only 18%, while in reality, it was 24%.

The 1980, 1985, and 1990 Energy Flow Charts

Since these charts represent projections into the future made by different organizations it is natural that they differ. The basic differences between the NPC and the USDI projections are that the NPC postulates a nuclear contribution comparable to official AEC projections, additional oil from secondary recovery techniques, and increased exploration for oil to reduce imports, while the USDI postulates a slower growth of nuclear energy with a greater dependence on imported oil to make up the difference between the domestic supply and demand. Also the USDI postulates only one demand level, but NPC postulates three: a low, intermediate, and high demand. As noted on the charts, the NPC intermediate demand (Case II) projection is chosen as the most likely scenario during the decade of the 1980's. The Appendix includes a discussion of the rationale for choices of end-use efficiencies.

Implications of Information Given in the Charts

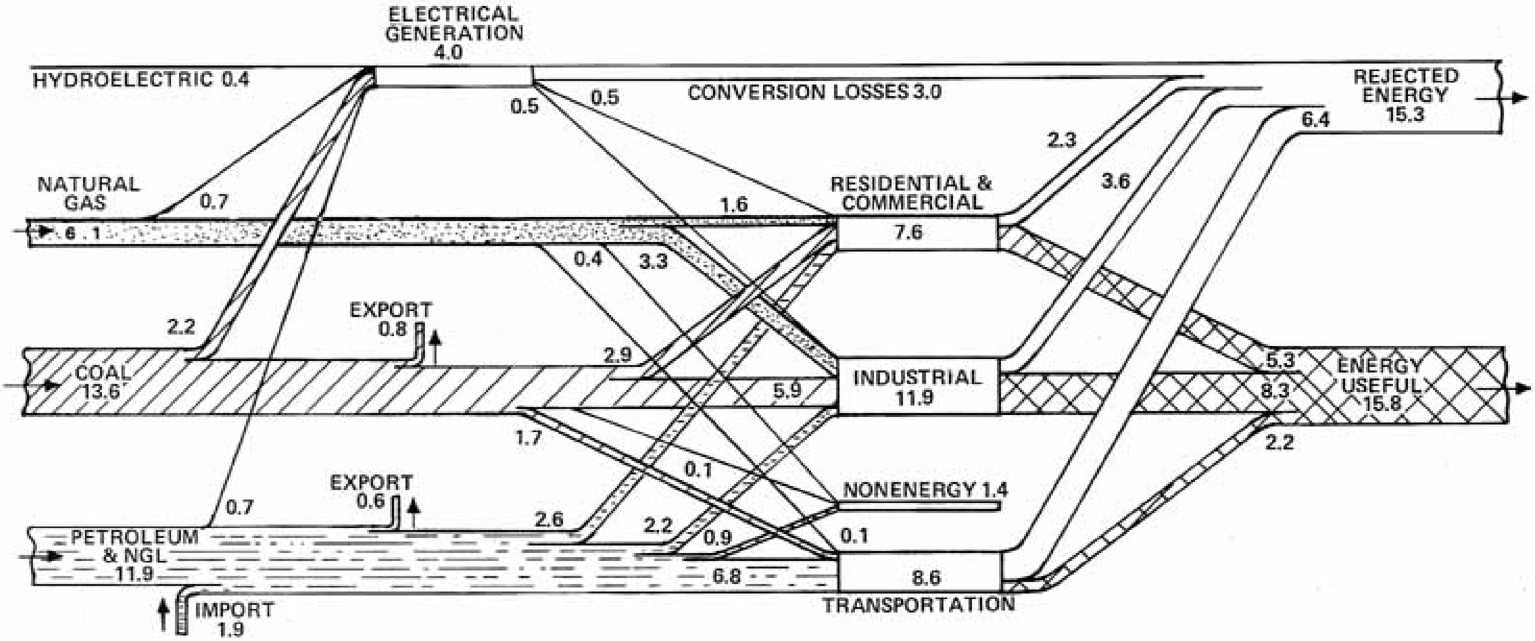
Briefly, these charts are a graphical presentation of energy usage over 40 years. They show which fuels provide how much energy and for what purposes. Their main value lies in the visual grasp they provide of a very complicated subject.

Upon examination of these charts, it becomes clear that they illustrate many of the basic characteristics of the "energy crisis." Some of the conclusions that can be drawn are that:

1. The national energy supply will continue to depend heavily on fossil fuels for some time. In comparison, the electrical output to the major energy markets remains relatively small— about 8-12% of the total energy supply.
2. The transportation sector is totally dependent on petroleum while in other sectors fossil fuels are interchangeable. By 1985 the transportation demand is expected to almost double, possibly itself exceeding the domestic supply of petroleum.
3. In 1970 about 25% of the petroleum was imported. By 1985, oil imports may exceed domestic production. This translates to about 4.7 billion barrels of oil, and at, say, $6/bbl, represents $28 billion outflow that year. Other data show that conventional domestic productive capacity (as well as the supply of oil and gas) is decreasing rapidly. Increasing gas and oil

supplies is the most critical problem. In any event, the cost of energy from gas and oil will probably increase.

4. By 1985 nuclear sources are expected to provide up to about 40% of the energy supplied for electrical generation (NPC projection). If, for some reason, this growth is inhibited, the difference will probably be made up from coal. This could lead to an economic and environmental dilemma resulting from mine safety problems, labor difficulties, dependence on strip mines, and control of plant effluents.
5. Nonenergy use of fossil fuels is relatively small (~6%). Nevertheless, petrochemical feedstocks are very important to the economy. Competition from the transportation sector may seriously affect petroleum availability for this purpose and increase costs of products from petrochemical sources.
6. The overall national energy efficiency is currently about 50%; i.e., the rejected energy component is about equal to the useful work. By 1985 efficiency will probably drop to about 40%. This is, in part, due to the inefficiencies in transportation. The internal combustion engine dominates the transportation sector, and probably functions at much less than the 25% efficiency shown.
7. Unless conversion efficiencies can be increased significantly, schemes to manage and utilize waste heat from power plants will be needed. A successful all-electric economy could evolve if high efficiency direct-conversion methods are developed, transmission losses and costs are lowered, and effective conversion of the major markets to electricity can be achieved. However, this seems unlikely to occur within this century.
8. Wider uses of coal and oil shale can relieve many of the emerging difficulties. Coal gasification is particularly attractive, but surface-based plants are dependent on the availability of strippable coal and water. The *in situ* process for both coal and shale has the advantages of low capital requirement, deep resource utilization, and minimum environmental impact. Hence, research and development on coal and shale utilization can yield significant payoffs. Economic methods of recovering secondary resources, such as partially depleted reserves, tar sands, and heavy oils will become increasingly important.
9. An alternate approach is to legislate the problems away by somehow bringing about a change in demand for energy. This is a socio-politico-economic matter which is not effectively addressed by a strictly technical approach. It should be noted, however, that energy conservation is probably the most effective means of relieving the dependence on imports in the 1970's because new energy technologies will likely not be commercially feasible until the 1980's. One technology which *could* have an early effect would be stack-gas removal of sulfur oxides, permitting coal to be used instead of low-sulfur oils to generate electricity.



U.S. Energy Flow — 1950

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 33.9×10^{15} Btu.

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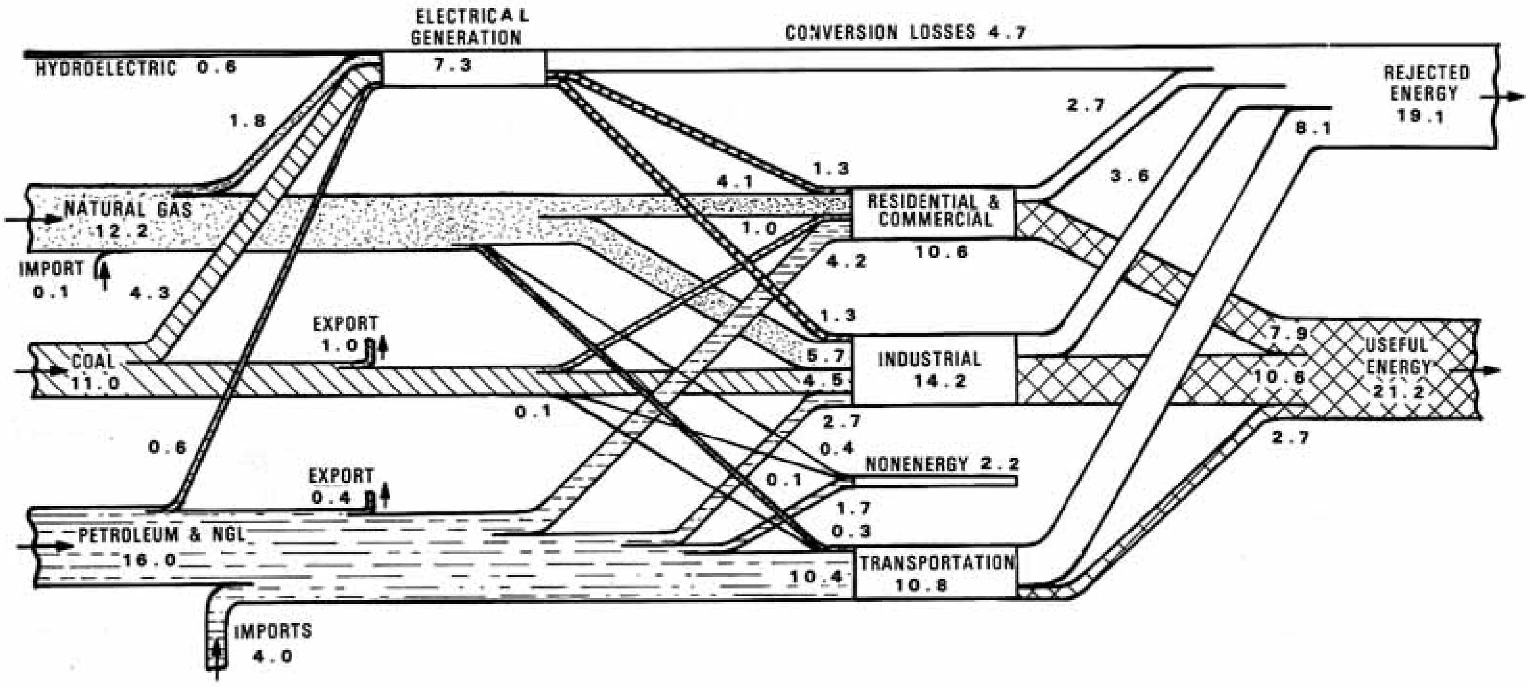

U.S. Energy Flow — 1960

All values × 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 43.9×10^{15} Btu

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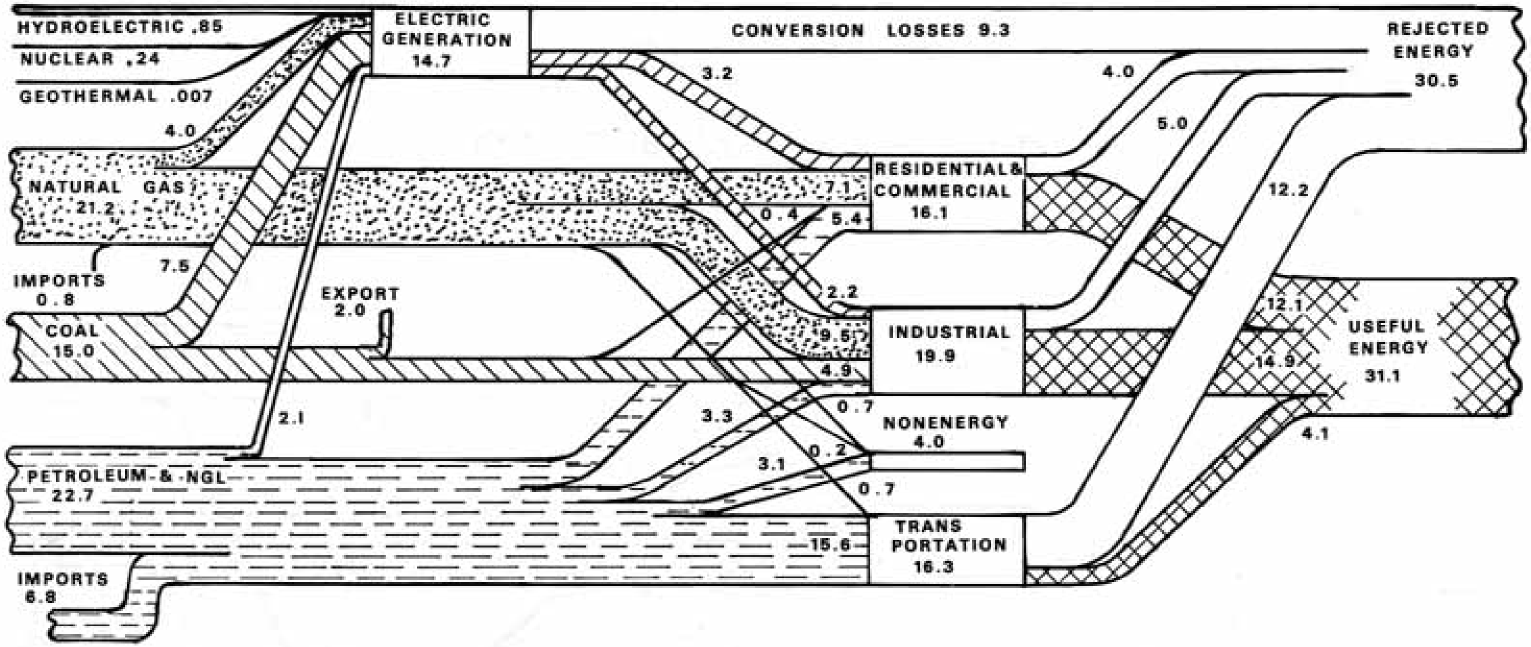

U.S. Energy Flow — 1970

All values × 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 67.5×10^{15} Btu

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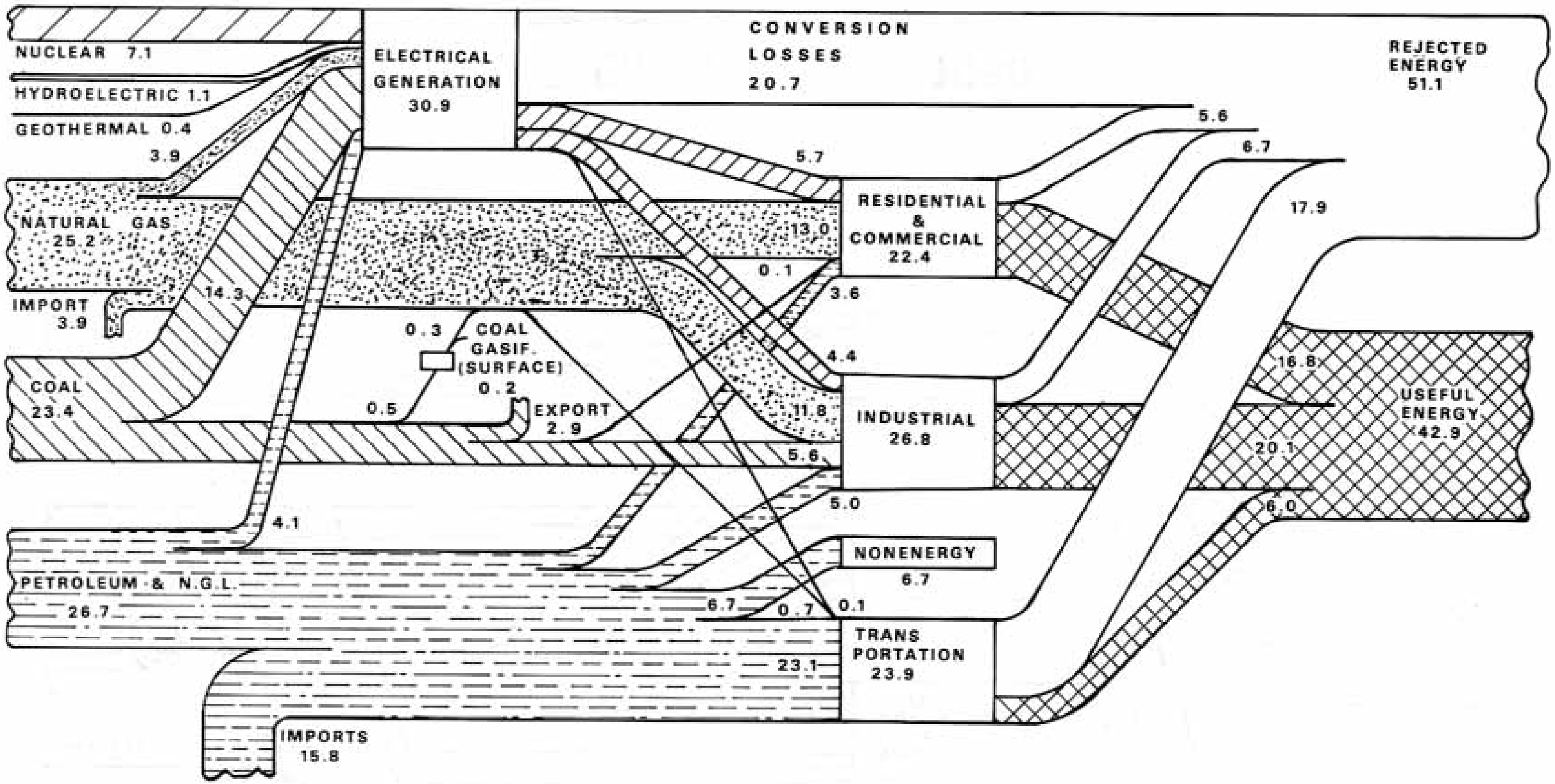

U.S. Energy Flow — 1980

Modeled after NPC Case II Intermediate Demand

All quantities 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 103.6×10^{15} Btu

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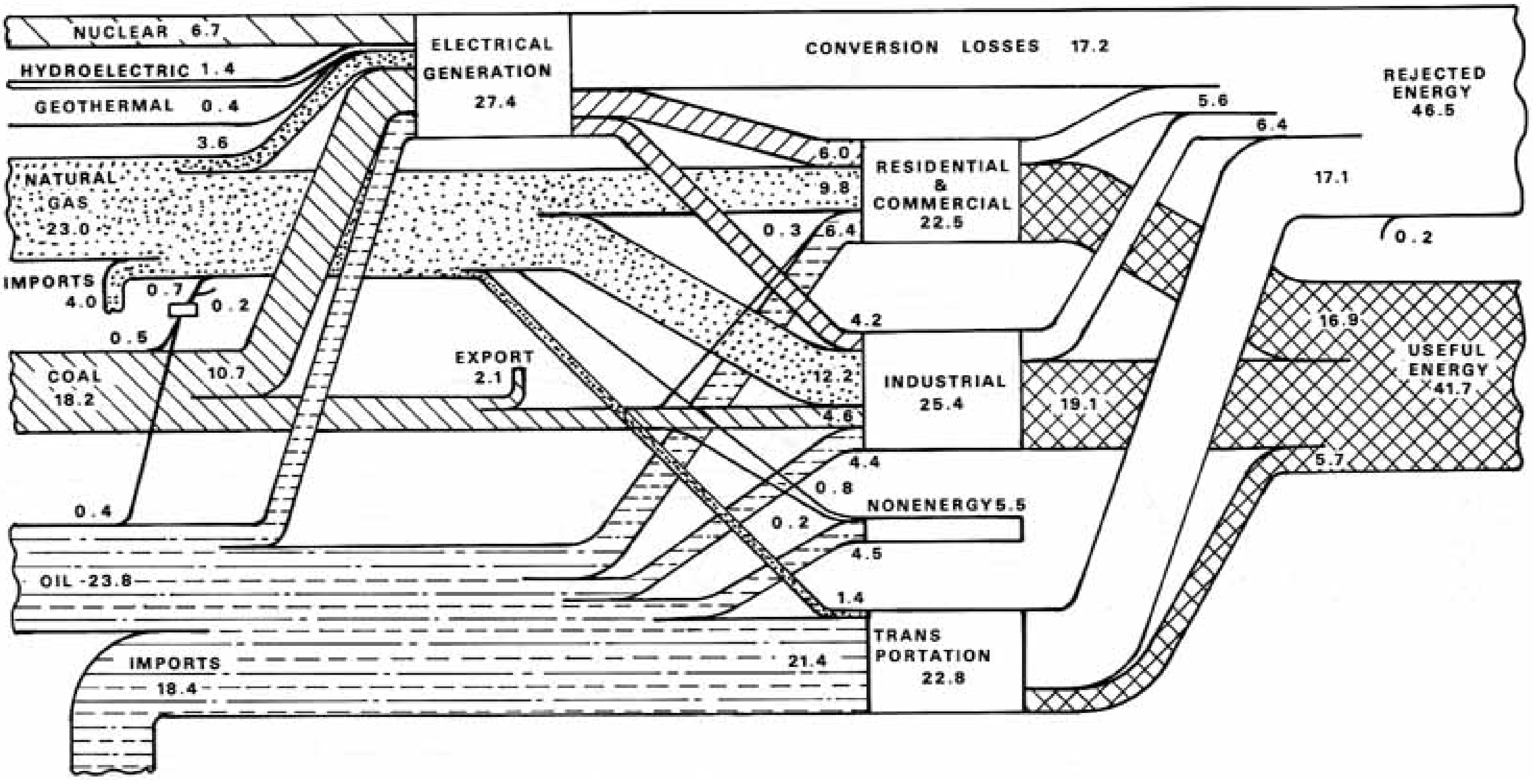

U.S. Energy Flow — 1980

Modeled after U.S. Dept. of the interior projection

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 95.9×10^{15} Btu

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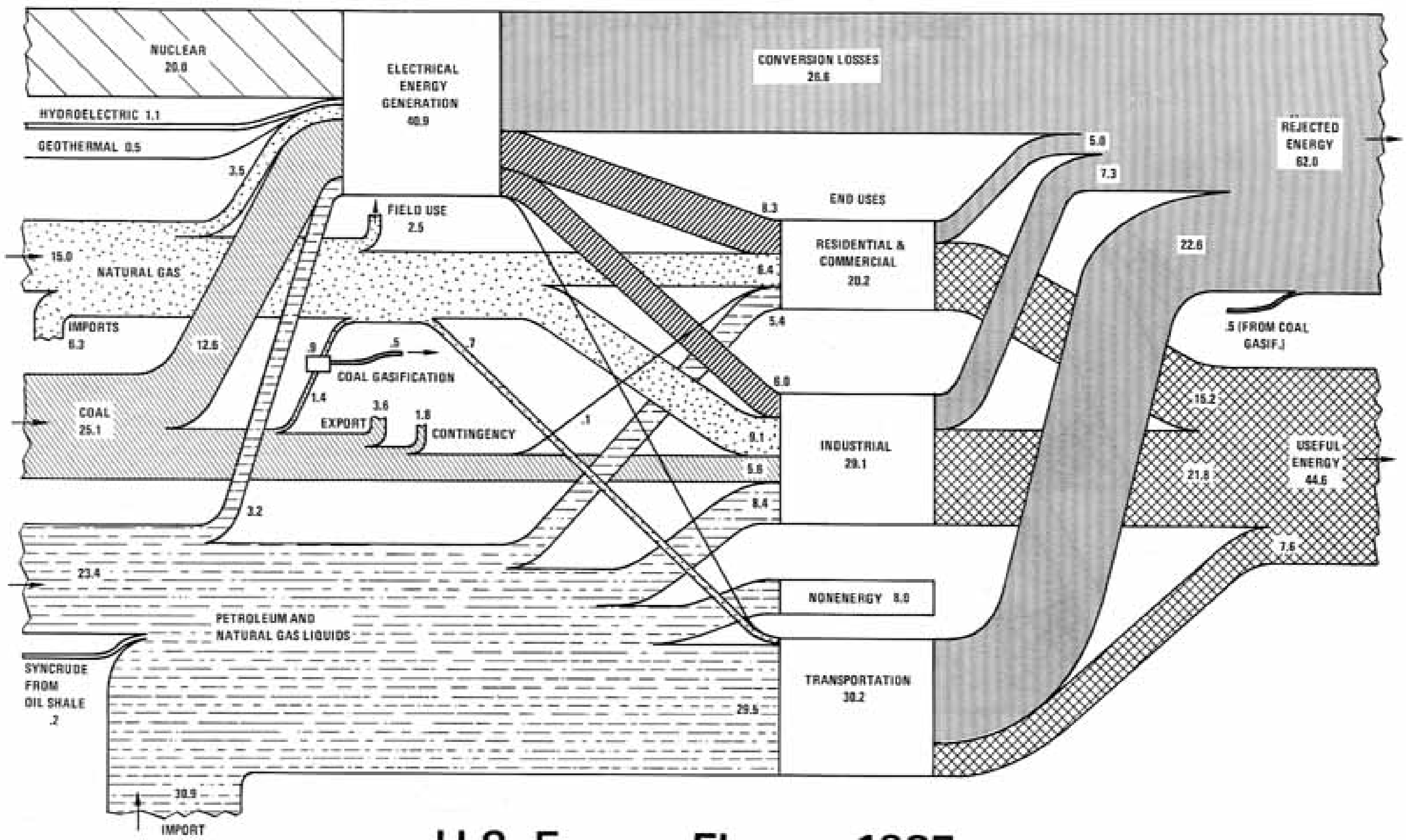

U.S. Energy Flow – 1985

Modeled after NPC Initial Appraisal

All values in 10^{15} Btu. (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 122.5×10^{15} Btu

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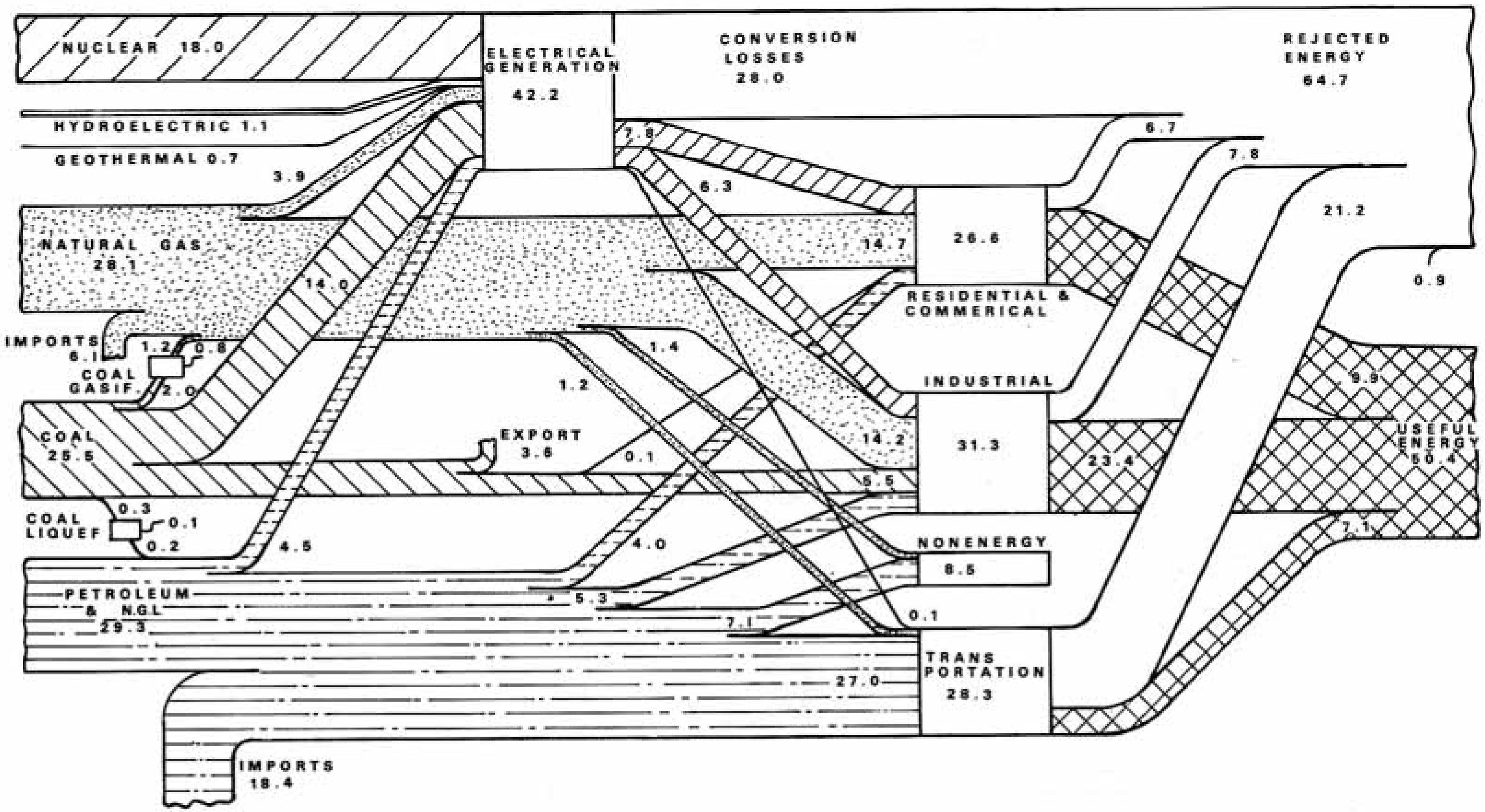

U.S. Energy Flow — 1985

Modeled after NPC Case II Intermediate Demand

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 127.2×10^{15} Btu

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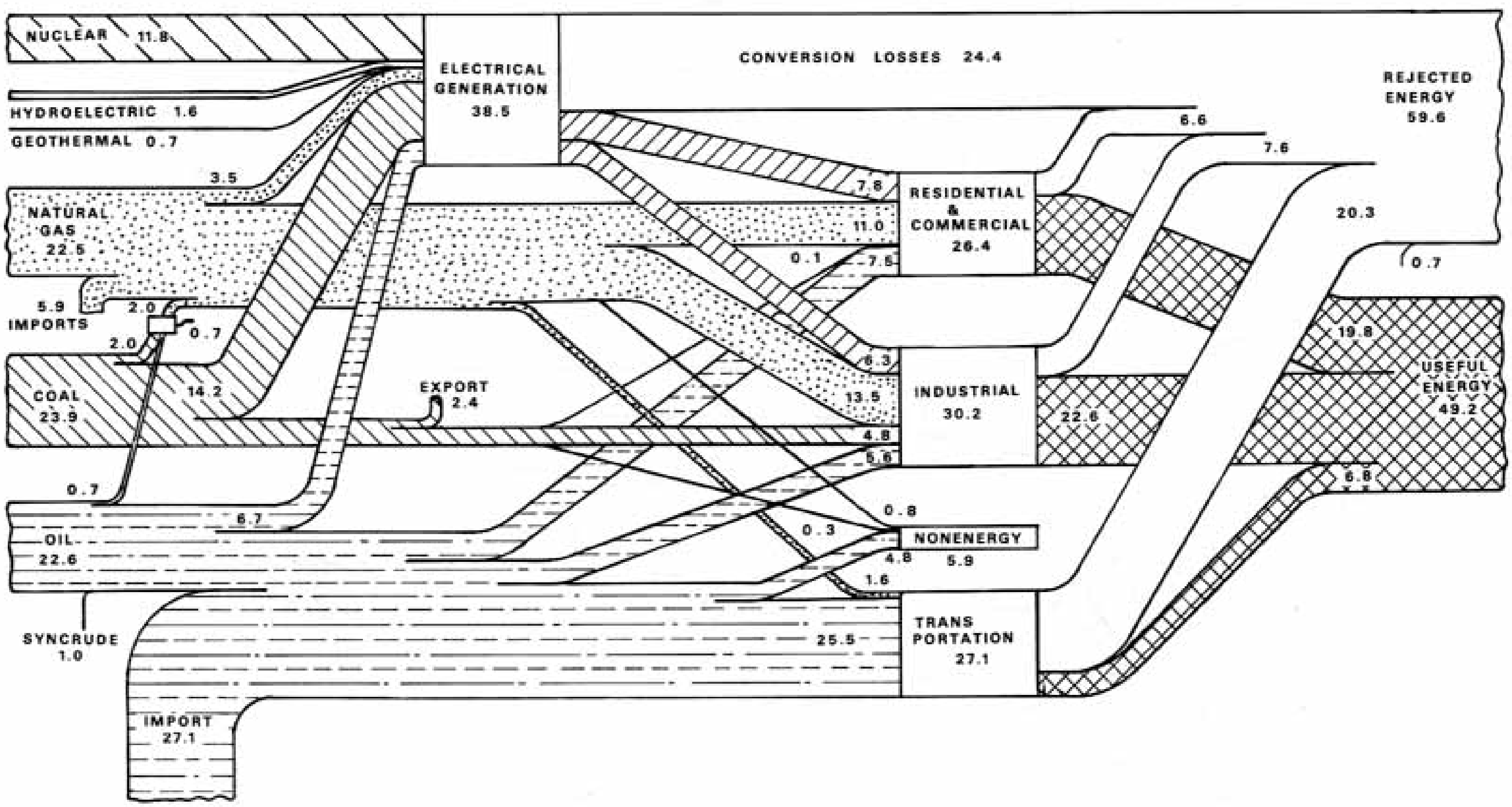

U.S. Energy Flow — 1985

Modeled after U.S. Dept. of the Interior projection

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^{6} bbl/day oil)

Total energy consumption = 117.1×10^{15} Btu

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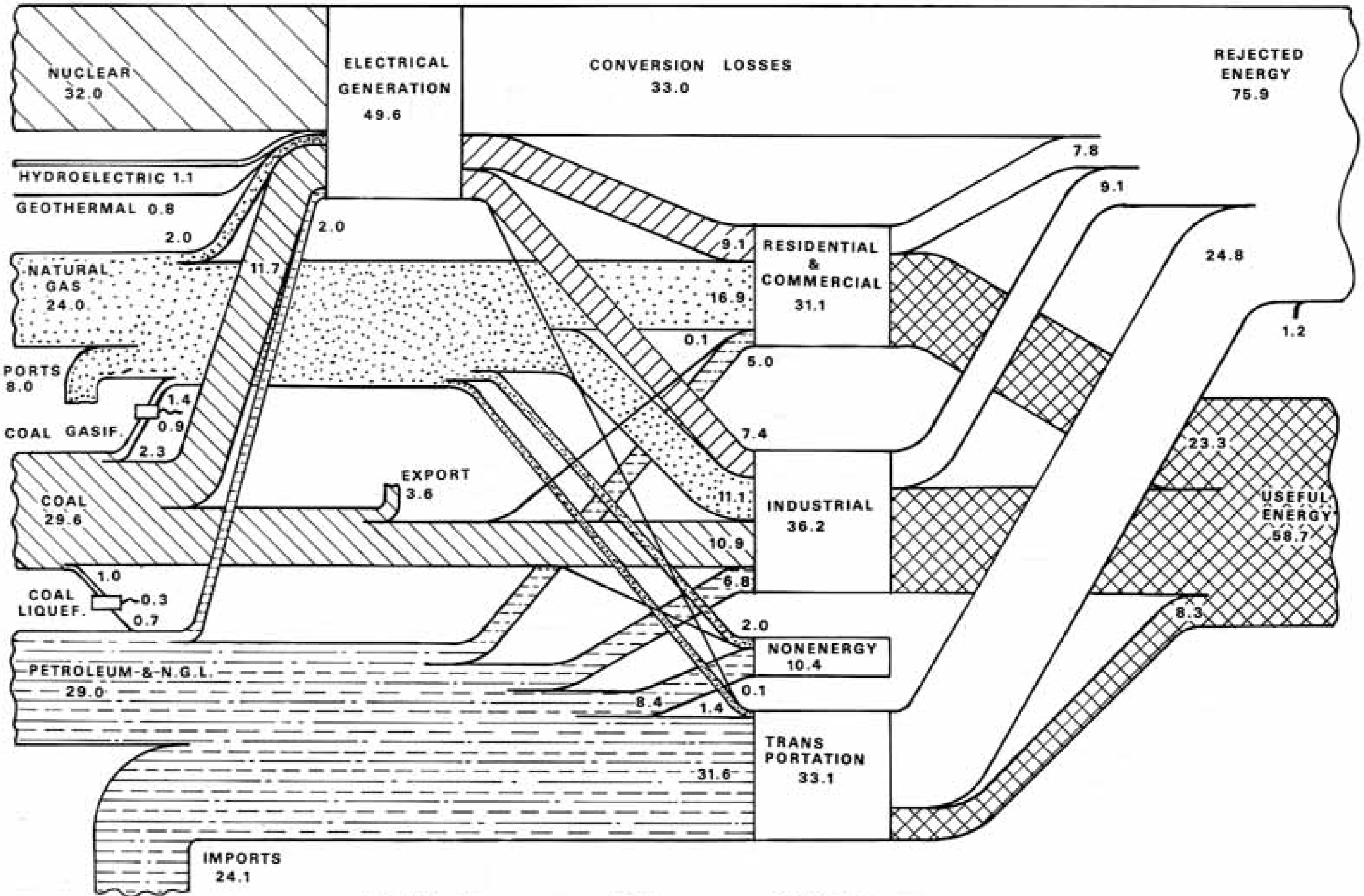

U.S. Energy Flow — 1990

Modeled after NPC Intermediate Demand Case

All values in 10^{15} Btu (2.12×10^{15} Btu = 10^6 bbl/day oil)

Total energy consumption = 148.6×10^{15} Btu

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Appendix
Example of Chart Construction

Experience has shown that innumerable questions will arise about how the numbers on the charts were obtained. In order to assist the reader in developing his own analysis, it seems worthwhile to explain one such chart in detail. This is particularly useful since translation of the data from the NPC report to the chart is not readily obvious. The following describes the construction of the 1985 NPC energy chart (all page and figure numbers following are those of "U.S. Energy Outlook—A Summary Report of the National Petroleum Council."[4]

CONSTRUCTION OF THE 1985 (NPC) CHART

1. The fuel mix for electric utilities is given on p. 20. Subtract 0.7 units (0.7×10^{15} Btu) of geothermal energy (from p. 30, Table II) to give the nuclear energy total of 18.0×10^{15} Btu.
2. In accounting for hydroelectric energy, NPC and others use an equivalent thermal energy input; that is, the 3.3 units listed in the amount of thermal input required to supply the same amount of power. This seems inconsistent since hydroelectric energy will continue to exist as such and will not be replaced by fossil or nuclear energy.
3. The oil, gas, and coal units are taken from p. 20 as 4.5, 3.9, and 14.0, respectively. The total energy input, then, to electrical generation is 42.2 energy units.
4. The electrical energy input to the end-use sectors is taken from the footnote of Table 2, p. 16. This sets the conversion loss at 42.2 - 14.2 = 28.0 units which is different than the 30.2 given on p. 16. This discrepancy comes from the different ways of treating hydroelectric power.
5. Because the distribution of gas, oil, and coal to the residential/commercial, industrial, and transportation sectors is not given in the NPC summary report,[4] Vol. 2 of the NPC initial appraisal[*] was used as a guide. First, the coal demand of 5.5 to the industrial sector was taken from Table LXXXVI, p. 127 of Ref. 8, with exports of 3.6 units taken from Table LXXXVIII, p. 128, using a conversion of 26×10^6 Btu/ton of coal. The oil distribution was taken from Table VII, p. 16, Ref. 8, but modified in proportion to fit the oil supply noted on the chart. The gas distribution was taken from Table LXVII, p. 100, but again modified arbitrarily in proportion to give the correct end-use sector totals from Ref. 4, p. 16. The oil and gas distributions were arbitrarily selected with the view that gas is a clean, convenient fuel and would most likely find widest use in the residential/commercial and industrial sectors.
6. The quantities of synthetic fuels from coal were taken from Table II, p. 30,

[*] U.S. Energy Outlook—An Initial Appraisal, 1971-1985, Vol. 2, National Petroleum Council, Washington, D.C. (1971).

Ref. 4. However, in order to derive the primary coal energy input, conversion efficiencies of 60% for coal gasification and 67% for coal liquefaction were used. These are as noted in the chart. The total additions to rejected energy is shown as 0.9 units.

1985 INITIAL APPRAISAL PROJECTION

The 1985 chart taken from the NPC Initial Appraisal Report[3] is included here only for a comparison purpose. The basic difference is that it assumes lower domestic production of oil and gas with the difference made up by oil imports; i.e., oil imports are set at 30.9×10^{15} Btu compared to 18.4×10^{15} Btu, as in the previous case.

THE 1990 CHART

This chart was constructed by extrapolating from the 1985 figures using a 3.2% growth rate in energy demand (p. 65, Ref. 4), taking the average of the expected energy supply figures for the year 2000 (p. 69, Ref. 4) and interpolating to 1990, and making up the difference with imports. The energy inputs to the end-use sectors were all increased by the growth rate factor of 3.2%. This procedure is obviously open to question since it does not account for significant growth in new supplies of energy from a concentrated research and development program. Hence, the impact of new technologies is not included.

CONVERSION EFFICIENCIES

Perhaps the greatest uncertainty in all of the charts is the choice of efficiencies for defining useful and rejected energies from the end-use sectors. The term rejected energy is specifically chosen so as to be consistent with the technical thermodynamic definition of the efficiency of an energy conversion process. The efficiencies shown are arbitrarily chosen, but are generally consistent with engineering handbook values for conversion devices such as process heaters, boilers, and internal combustion engines. Hence, the residential/commercial and industrial sectors are arbitrarily set to operate at 75% efficiency. The internal combustion engine is the major consumer of transportation energy (~75% in 1970). Without emission controls and operating at optimum level, an internal combustion engine has a brake thermal efficiency of about 25%. Even though this is probably the maximum achievable efficiency, it is arbitrarily selected here as the overall transportation sector efficiency. No attempt has been made to define use efficiencies which would account for losses due to idling, emission control systems, spillage, poor maintenance, and non-optimum operation. If all these factors were to be included, the overall transportation efficiency of energy use would be closer to 10%.

The quantifying of use efficiencies is a study in itself, cutting across technical, economic, and sociological boundaries, and should be addressed further. For the present, however, we are left with our perhaps overly simplified definitions. Hence, the reader is invited to draw his own conclusions regarding the distribution of useful and rejected energies. It should be noted that all the charts from 1950 to 1990 incorporate the use efficiencies noted above.

It is hoped that the above comments and the "recipe" for producing one of these charts will assist the reader by removing some of the apparent ambiguities which appear when one compares our charts with the NPC and USDI reports.

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