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World Energy Perspective

W. R. Gambill

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Chemical Technology Division

WORLD ENERGY PERSPECTIVE

W. R. Gambill

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FOREWORD

This perspective was prepared in 1983 for the Program Planning and Analysis Office of ORNL. The initial draft report was completed in November 1983 and subsequently updated in May 1984. The only changes since that time have been minor ones of an editorial nature and a few statistical additions through December 1984. To preserve the content of the original version, and because the author thinks that subsequent events have changed none of the primary conclusions, no additional changes have been made to the manuscript.

ABSTRACT

Projections of global total energy and electrical energy consumption rates based on Stewart's model of cycle-adjusted-logistic growth are presented and discussed. Time intervals required for supply and demand in the U.S. fluid fuels sector to balance are estimated.

The provisional global energy projection for the coming decade is one of low growth rates accompanied by economic adjustments and difficulties and falling energy prices. The projection for the first quarter of the twenty-first century reflects a cyclic reversal to sharply increased economic activity, energy demands, fuel prices, and pressure on the technological sector to provide an adequate energy supply.

Implications for the developing nations and for the U.S. and world economies are briefly addressed.

1. SCOPE

The intent of this study was to project global energy production/consumption patterns, with emphasis on the next ten years, taking into consideration the significant changes in these patterns that have occurred over the past five years. All long-range energy projections should be viewed as best estimates based on current knowledge, not as forecasts or necessarily valid predictions.

2. PROJECTION METHODOLOGY

In this perspective, projections of future total and electrical energy consumption depart from those presented in most studies. Typically, such energy-growth projections result, regardless of the initial assumptions, in a logistic curve - i.e., a pseudo-exponential curve with a growth coefficient uniformly decreasing with time. When plotted on linear coordinates, a logistic curve takes the shape of an elongated "S" curve (a sigmoid or Gompertz curve). To the extent that such a curve depicts how growth can saturate over time, it is useful and realistic. However, such projections always indicate mature growth rates decreasing monotonically with time, and historically observable fluctuations in energy growth are ignored. One example of how inaccurate an informed, conventional forecast can become, eleven years later, is that of H. R. Linden, published[1] in 1973. This study projected a total primary energy consumption in the U.S. of 228 quad (10^{15} Btu) in the year 2000. The subject consumption rate is now anticipated to be only 1/3 to 1/2 of the cited projection, as discussed in a recent report[2] which emphasized the energy future of the United States through the year 2020.

An alternative projection methodology that also better describes past trends has been proposed by Stewart in his book concerning transitional energy policies,[3] in a later booklet,[4] and in two papers.[5,6] His approach is based on the observation that the growths of both total energy and electrical energy consumption in the U.S. (since 1850 for the

former and 1905 for the latter) have exhibited a cyclic variation about a median logistic growth or trend curve. Stewart plotted historical annual energy-consumption data as 5-year moving-average points and then developed a compelling correlation[3,6] of the temporal variation of the percentage deviation of the data points from the logistic curve, as shown in Fig. 1 for data through 1980. Over 70% of the data points fall within the shaded area - i.e., within a ±5% band around a sinusoidal curve having an amplitude of 20% about the logistic curve and a period of 54 years. The subject 130-year period saw the growth of entirely new industries and technologies and the decline of old ones as well as many social and institutional changes in the structure of industry and government. This indicates rather conclusively that energy consumption grows in surges or cycles rather than uniformly.

Similar correlations based on world energy data have also been developed,[3] but it is noted that evaluated data at the global level that can be considered reasonably reliable extend only from about 1920 for electrical energy and from about 1940 for total primary energy. In addition, the cyclic variations in world electricity consumption about the global trend curve appear to be smaller than those for the U.S. above and below the U.S. logistic curve. Because of the varying positions of different nations on the logistic energy growth curve at a given time, this result appears reasonable.

Stewart discusses[3,6] possible linkages between his work on cyclic variations in energy growth and the analytical studies by Mensch[7] of the University of Berlin (now with Case Western Reserve University) and by Marchetti[8,9] of the International Institute for Applied Systems Analysis (IIASA) on a long economic cycle resulting from the growth, saturation, and stagnation of basic industrial innovations. Similar studies of this type have been conducted by MIT's System Dynamics Group[10] and by the Science Policy Research Unit at the University of Sussex in England.[11] The growing literature concerning the so-called long economic (and, therefore, energy) wave, which has evolved from the seminal work of N. Kondratieff (1920s) and of J. Schumpeter (1930s), is reflected by a number of recent papers.[12-19] All of these relate, at least indirectly,

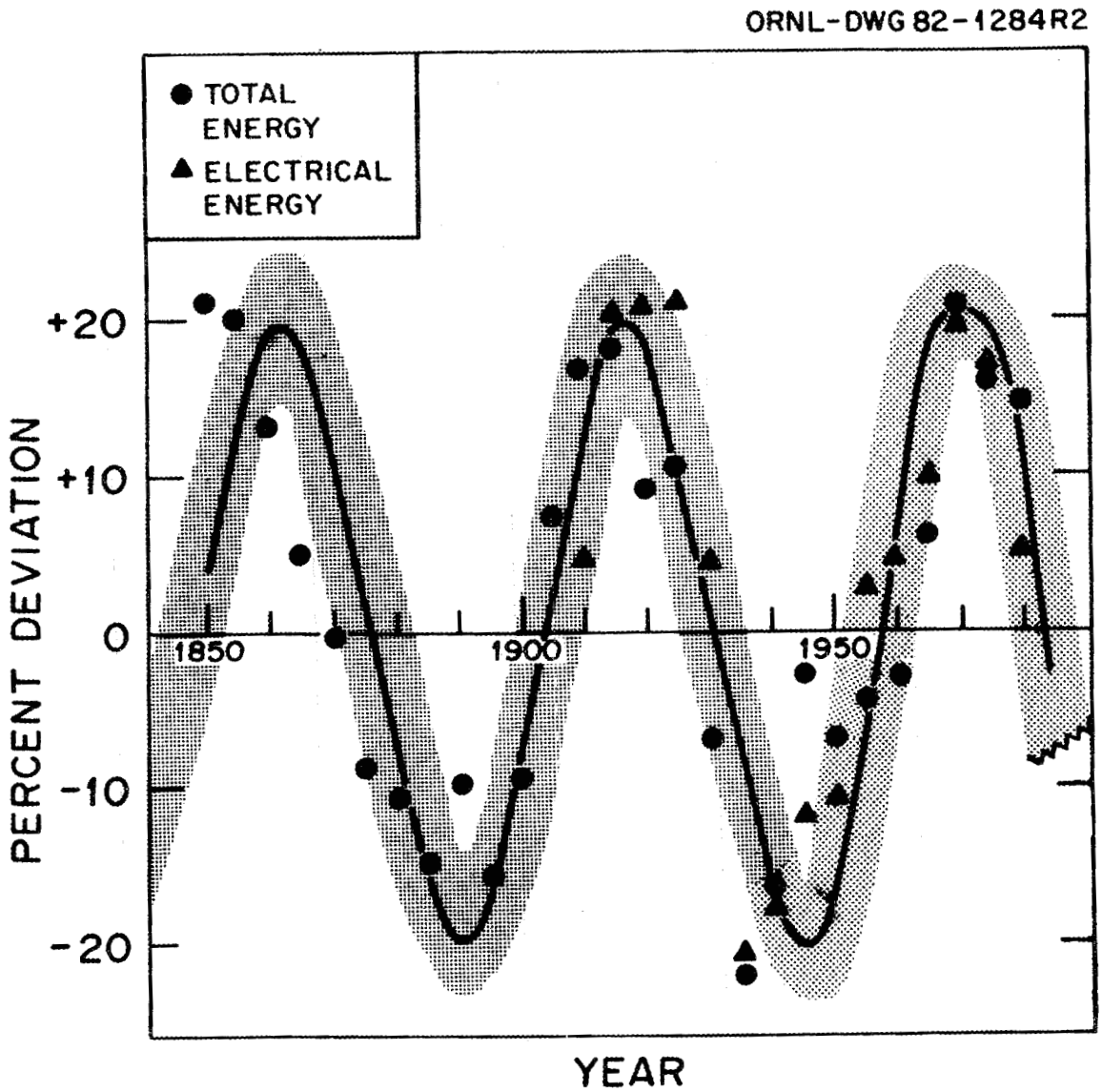

Figure 1. Deviation of U.S. historical energy consumption data from a logistic approximation.[6] Note the data points for 1980 showing a decline consistent with projections. (This is an updated version of a figure appearing in Transitional Energy Policy,[3] Pergamon Press, 1981.)

to analyses of economic movements with life spans (periods) of 40-60 years. The period of 54 years characteristic of Fig. 1 appears not to be coincidental.

3. OVERALL CAL PROJECTIONS

Stewart has applied the cyclic pattern of energy growth depicted in Fig. 1 to projections of future U.S. and world energy consumption rates according to what he calls the cycle-adjusted-logistic growth, or CAL growth. The result[3,5] for the U.S., which is described in some detail in ref. 2, indicates a relatively flat total energy consumption rate until about the year 2000 (actually declining somewhat until ~1992), with electrical energy growing at ~2.5% p.a. during the same period [cf. U.S. power generation growth rates of 7.5% p.a. (1950 to 1970)[3] and of 2.2% p.a. (1973 to 1983)[20]]. The CAL projection indicates that total primary energy consumption will not return to its 1979 peak of 79 quads until about the year 2003. The CAL curve, however, also projects a very rapid energy growth rate between the years 2000 and 2025 that will more than make up for the relative stagnation between 1980 and 2000. Quoting Stewart:[5] "It is crucial, though, that society does not get complacent if total energy use temporarily levels out; i.e., we must continue to plan for the future in order that we can meet our energy needs and growth after the year 2000." Restated, past overestimates of present energy consumption rates could change easily to current underestimates of future (post-2000) consumption rates.

CAL energy projections[3] for the world (and the U.S.) are shown in Fig. 2 for total energy consumption to 2025 and in Fig. 3 for electricity generation to 2050. In each figure, the logistic curves (long-term trends) are given by the dashed lines and the CAL projections by the solid lines.

With regard to <u>world total energy consumption</u> (Fig. 2), five major points emerge:[3]

- Energy growth in the U.S. is more nearly approaching saturation than is that of the world - i.e., world energy consumption is on a higher growth rate part of the logistic curve.

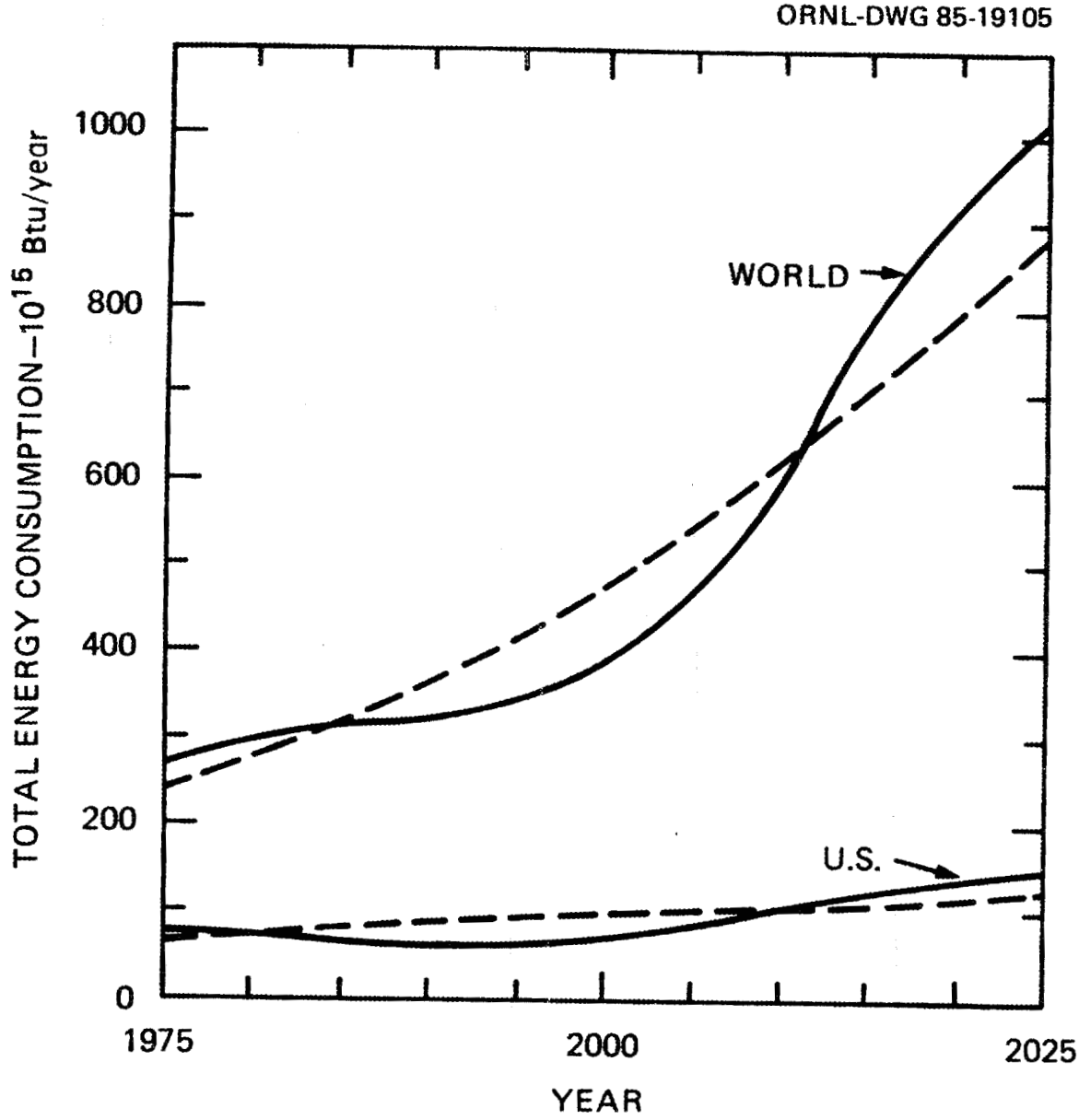

Figure 2. World and U.S. growth curves for total energy consumption. Logistic (dashed) and CAL (solid).

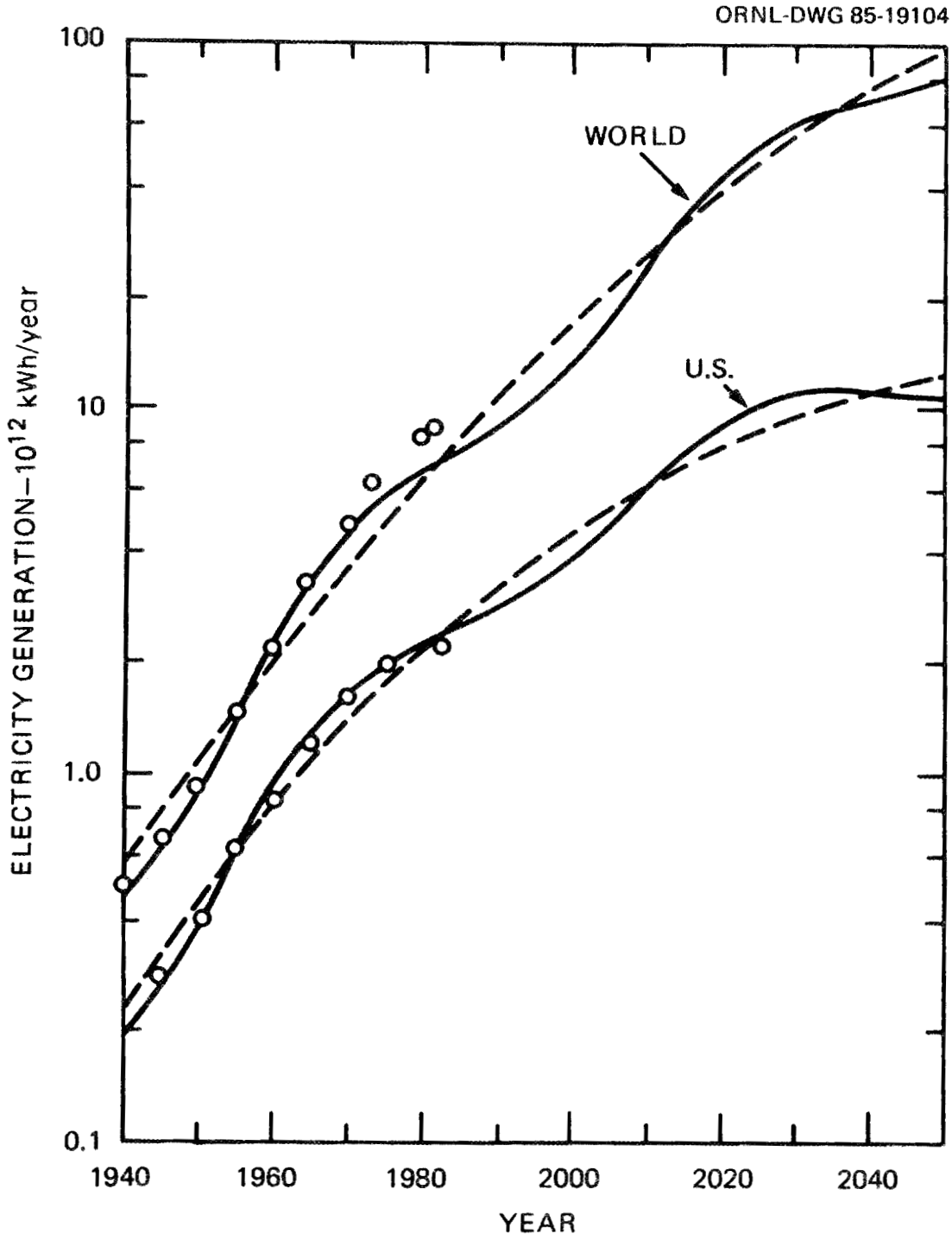

Figure 3. World and U.S. growth curves for electricity generation. Logistic (dashed) and CAL (solid).

- CAL growth rates for the period 1975 to 2000 are 1.4% p.a. for the world and zero for the U.S.; for the period 2000-2025, the corresponding rates are 4.1% p.a. and 2.8% p.a. The actual global growth rate, 1860-1980, was 2.3% p.a.

- For the interval 1975-2000, the 40% CAL growth indicated for the world suggests a 60% growth for the world outside the U.S., or a rate of 1.9% p.a. The subject energy growth for the rest of the world (ROW) would be greater than the total U.S. energy consumption in 2000.

- If the past CAL pattern of energy growth continues, the increase in the ROW will continue at a relatively high rate even if the growth rate for the U.S. until 2000 is indeed essentially zero.

- For the high growth rate period 2000 to 2025, nuclear energy appears to be the only assured candidate - of the energy technologies currently available - to meet the very large incremental requirements indicated. While a decision for the further deployment of nuclear energy may not be necessary in the near future in the U.S., the need for such a decision appears to arise earlier for the ROW.

Concerning world electrical energy consumption (Fig. 3), there are also five major conclusions:[3]

- Energy resources required for power generation will be of long-term primary importance because of increasing electrification - i.e., the fraction of total energy consumption used for power generation will continue to increase, reaching ~50% in several countries by 2000. For the world, the historical trend[21] based on IAEA data is shown below:

Year	1950	1960	1970	1980
Thermal input to electrical energy consumption, as % of total energy consumed	12.4	18.6	25.0	29.1

For the U.S., the trend is similar, the subject fraction having increased from 16% in 1952 to 35% in 1983.

- U.S. power generation decreased from 43% of world generation in 1946 to 26% in 1982, and the long-term CAL projection is to less than 20% by 2025. Again, likely world energy growth is much larger than that for the U.S.

- The U.S. fraction of world installed nuclear generating capacity, which was 36% at the end of 1982 (IAEA data),[22] will decline, by CAL projections,[3] to about 28% in 2000 and to 18% in 2025.
- The growth of power consumption, which has fallen sharply relative to the 1950-1970 level, will probably remain small for another 10-12 years (~3.2% p.a. for the world). The decreased number of power stations being planned practically ensures this outcome. The CAL projections of world and U.S. net addition rates[3] (not including replacement plants) - not shown here - fall to minimum levels, around 1990, of 30-50 GWe/year (world) and 3-5 GWe/year (U.S.).
- The short-term hiatus will likely be followed, beginning 1995-2000, by a very large demand upswing.

3.1. SUMMARY OF GLOBAL CAL PROJECTIONS

This methodology indicates near-term (1980-2000) consumption growth rates of approximately 1.4% p.a. for world total energy, 1.9% p.a. for ROW (world outside U.S.) total energy, and 3.2% p.a. for world electrical energy.

3.2. SUPPORTIVE STUDIES

A number of world energy evaluations support the relatively low growth rates projected by the CAL methodology for the period 1980-2000. Several of these projections are described and compared in the material that follows.

a. Alcock conducted a cyclical analysis[23] of the world economy based on total energy consumption per capita rather than the more usual real GNP per capita. The analysis was based on data for the 12 largest wealthy nations (which accounted for 75% of the world GNP): USA, Canada, UK, France, FRG, Poland, Czechoslovakia, Italy, USSR, Sweden, Japan, and Australia. The independent variables were five sinusoidal cycles with fixed periods and a composite cyclical index composed of the five cycles equally weighted. For one pre-WWII interval (1922-1938) and one postwar period (1950-1966) - a total span of 32 years - the composite index accounted for 97.5% of the variance of total energy consumption per capita. When applied outside these two time spans used for the multiple

regression analysis, the model accurately "predicted" the steady growth of the forties and the deep recession of 1973-77 (especially 1973-75). The average growth rate projected for 1977-2001 (and for 1983-1993) is 0.60 ($\pm$0.1) % p.a., a rate about one-fifth of that characterizing the period 1950-1966, and described by the author as "slow growth - close to stagnation."[23]

The rate of change of total energy consumption for this world sector may be estimated by combining Alcock's rate for energy consumption per capita with the estimated rate of population growth for the same (or a similar) sector. For the latter factor, IIASA's population growth estimate[24] for its 17 NMOs (national member organizations) was selected because the countries involved are quite similar to those chosen by Alcock. The NMOs are: Austria, Bulgaria, Canada, Czechoslovakia, FRG, Finland, France, GDR, Hungary, Italy, Japan, Netherlands, Poland, Sweden, USSR, UK, and the USA. For this group of nations, the estimated population growth rate, 1980-2000, is only 0.60% p.a. This yields a projected growth rate of total energy consumption for the "wealthy nation sector" of (1.006)(1.006), or 1.20% p.a. Since the IIASA NMO population is expected to constitute 18% of that of the world in 2000, combination of this growth rate with the global CAL projection of 1.4% p.a. indicates a "poor nation sector" growth of 1.44% p.a. This secondary projection should not be accorded undue significance, however, since it is based on two forecasts which utilize quite different methodologies.

b. The recent IIASA analysis for the European Community (EC) Commission of the long-term energy future of the countries of the European Economic Community has been summarized by Wolfgang Sassin.[25] A major conclusion is stated as follows:

> "The study found previous investigations of the European energy future to be optimistic with regard to economic growth rates and import opportunities as well as conservation potential. In IIASA's macroeconomically balanced scenarios for the EC, a substantially lower economic growth rate is projected, declining steadily over time though remaining positive, and it is against this background that the EC's energy system will have to be restructured."

For the period 1975-2030 (the only interval for which estimates are presently available), growth rates projected for the EC were 1.10% p.a. for final total energy, 2.07% p.a. for final electrical energy, and 1.57% p.a. for real GDP per capita.

c. In IIASA's massive "Energy in a Finite World" study,[26] published in 1981, the global total primary energy growth rates for 1975-2000 are 2.91% p.a. in the High Scenario, 2.04% p.a. in the Low Scenario, and 1.75% p.a. in its "Minimum Scenario," which corresponds to per-capita total energy consumption remaining constant during the subject period. The distribution of final energy demand through the year 2030 among 6 of the 7 world regions considered in the IIASA study has been addressed by Khan and Hölzl.[27] The momentum of the current energy consumption trend and the other projections cited suggest that the minimum projection made by IIASA will prove to be the most accurate of the three.

d. S. Hultin, chairman of the international executive council of the World Energy Conference, has proposed[28] "an optimistic scenario" which corresponds to a world total energy growth rate for 1978-2000 of 2.21% p.a.

Assuming a real gross world product (GWP) growth rate (1981-2000) of 3.0% p.a., J. H. Lichtblau arrived at similar conclusions.[29,30] His projections of average growth rates for total energy consumption span a narrow range: 2.04% p.a. for market economies, 2.20% p.a. for the USSR, 2.46% p.a. for all centrally planned economies, and 2.17% p.a. for the world.

e. Some relatively recent projections (July 1983 forward) for individual countries, in no particular order, include the following tabulated values:

Table 1. Projections of Regional Energy Growth Rates

Nation	Consumed energy form	Time interval	Projected growth rate (% p.a.)	Reference No.
UK	Total	1982-2000	0.7	53
Japan[a]	Total	1982-1990	2.2	50
		1982-1995	1.9	31
E. Germany	Total	1986-1990	<1	32
U.S.	Total	1982-2000	1.0	33
	Electrical	1982-2000	2.3	33
U.S.[b]	Total	1982-1995	1.0	39
Israel[c]	Electrical	1983-2015	3.8	54
Switzerland	Electrical	1983-1990	~3.0	55
Spain	Electrical	1984-1992	3.3[d]	34
			4.3[e]	56
W. Europe[f]	Total	1982-2000	1.9	57
Taiwan	Electrical	1984-2000	6.3	58
Ontario Hydro service area	Electrical	1984-1998	2.4	59

[a]Japanese government estimates.
[b]Projection by Ross of Petroleum Industry Research Associates., Inc.
[c]Forecast by the Horev Commission.
[d]Spanish government estimate.
[e]Projection of Spanish utilities association (UNESA).
[f]Forecast by Data Resources, Inc.

3.3. SUMMARY OF PRECEDING GLOBAL PROJECTIONS

The outlook emerging from the studies cited is one of relatively slow growth for the remainder of the century. For total primary energy, anticipated average rates are approximately 1.5-2.0% p.a. for the world and 1.0-1.5% p.a. for the presently industrialized nations (the U.S. and Western Europe, e.g.). For electrical energy, the corresponding average rates are 3.0-3.5% p.a. (cf. 4.0% p.a. for 1973-1981) and 2.0-2.5% p.a. These ranges are consonant with the projections of the primary CAL methodology.

4. THE FLUID FUELS SECTOR

4.1. OIL

The present situation is reflected by the decrease in world oil production[35] from its peak of 62.40 million bpd in 1979 to a level of 51.22 million bpd in H1/1983, a decline of 17.9%. Of this recent total, 35.31 million bpd was produced by non-OPEC nations and 15.91 million bpd by OPEC (a decrease of 49.1% below OPEC's peak rate of 31.23 million bpd in 1977). Total Communist Bloc production (H1/83) was 14.93 million bpd; of this, the USSR produced 83%. Of the USSR's oil exports of about 3 million bpd, 1-1.5 million bpd are sold to non-Communist countries.[36]

The primary constraint to any significant near-term increase in world oil prices appears to be the large excess of production capacity over consumption rate. Quoting J. F. Bookout, the president of Shell Oil Co.:[37] "To sum up the situation, what we have witnessed in these past few years is the taming of the free world's appetite for oil. While this was occurring, oil supply was being added. The result is that present free-world production capacity, OPEC and non-OPEC, is <u>at least 10 million barrels a day higher</u> than present demand [emphasis added]. That large surplus of capacity has short- and long-term implications for producing and consuming nations." My own estimate of the minimum capacity excess for the entire world, based on data[35] available through June 1983, is 11 million bpd. Other estimates of world excess capacity are as high as 15 million bpd (from an API paper presented in August 1983 at the World Petroleum Congress in London).[38]

Utilizing the lower estimates of excess capacity and June 1983 consumption,[35] the approximate free-world capacity-to-consumption ratio is (53.2×10^6 bpd/43.2×10^6 bpd), or 1.23.* The time required for supply (S) and demand (D) to balance is as follows:

Oil consumption growth, % p.a.	Time for S = D (year)	Year
1	20.8	2004
2	10.5	1994
3	7.0	1990
4	5.3	1988

For the entire world, the ratio of capacity to consumption is approximately (68.1×10^6 bpd/57.1×10^6 bpd), or 1.19, which leads to the following values:

Oil consumption growth, % p.a.	Time for S = D (year)	Year
1	17.7	2001
2	8.9	1992
3	5.9	1989

If estimates of world oil demand increasing at 1% p.a. for the remainder of the century prove valid, the cumulative consumption would be 387×10^9 bbl by my estimate and 404×10^9 bbl based on Lichtblau's projections.[29,30] In either case, the cumulative consumption would be ~55% of world demonstrated reserves of 723×10^9 bbl, which represents a current reserve/production ratio of ~35 years. The subject value for world proven oil reserves,[29,39] which is about 12% higher than previously reported estimates, represents an energy content exceeding 4000 quads. Although world oil reserves are slowly declining (discoveries less than production), the point is that global oil supply and demand might not be balanced until as late as the turn of the century. Such a respite would provide an opportunity to advance the development of longer-term sources of energy.

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*By the end of CY 1984, there was some indication that this ratio had fallen to about 1.18.

Representative recent projections of increases in oil demand include the following:

- For the U.S., Lichtblau[39] estimates 0% p.a. (flat) through 2000, Baggett[40] projects 1% p.a. (maximum) for 1983-1995, and Gustaferro[33] estimates - 0.9% p.a. for 1982-2000.
- For the free world, Treat[39] estimates 1% p.a. (1983-1993); for the entire world, Lichtblau[29-30] foresees an average rate (1981-2000) of 0.8% p.a.

These projections coincide semiquantitatively with the CAL forecast for total energy consumption and with the prevailing outlook that growth rates for real GNP and electrical energy will be about the same, that for total energy consumption smaller, and that for oil consumption even lower. As Lichtblau notes:[30] "...oil's relative importance in the energy market appears to be on a long-term....decline. In the centrally planned economies, this may be due primarily to supply constraints. In the market economies, the principal causes are structural changes in demand."

4.2. NATURAL GAS

In H1/83, world gas production[35] was at a rate of 58.3 TCF/year, 63% in the free world and 37% in communist nations. Halbouty recently estimated[29,39] that only one third of the world's ultimately recoverable gas has been discovered and that current proven reserves total 3191 TCF, which represents an energy content exceeding 3200 quads. Halbouty, a U.S. geologist and independent producer, thinks that both mature petroleum producing areas and the frontier regions of the world have a high potential for future gas discoveries, as well as extensions and reappraisals.

In the USSR, the reserve base of gas is much greater than for oil[36] - about 65 billion barrels of oil (9-10% of world reserves) cf. about 1165 TCF of gas (37-40% of the world total). Current production/consumption levels indicate 12-14 years of oil and over 70 years of gas. Scanlan of British Petroleum estimates[36] that by 1985, USSR gas production will roughly equal its oil production in thermal value, and that

the West Siberian/Ob Delta complex will be producing gas and oil equivalent to eight times the hydrocarbon production of Alaska or approximately the equivalent of total 1983 hydrocarbon production in the Arabian Gulf. Lichtblau[29] projects USSR gas production to increase at 5% p.a. to 1990 and by 3-4% p.a. during 1990-2000. This may be compared to his other estimated growth rates (1981-2000) of 2.37% p.a. (world), 3.60% p.a. (centrally planned economies) and 1.67% p.a. (market economies).

In the U.S., the excess capacity in the gas sector is well known. Foster, a Tenneco vice president, believes[41] that the total U.S. gas surplus is ~4 TCF/year - i.e., that the ratio of capacity to consumption is presently about (22 TCF/18 TCF), or 1.22,* which gives the following values for equality of supply and demand:

Gas consumption growth, % p.a.	Time for S = D (year)	Year
2	10.1	1993
4	5.1	1988
6	3.4	1987

The reasons for Foster's belief that a domestic gas surplus will last "until at least 1986" are clear. Gustaferro[33] foresees U.S. gas consumption flat through 2000 at ~17.9 TCF/year, the 1982 rate. In 1983, the U.S. consumed 17.0 TCF of natural gas, a level expected by many to rise to ~18 TCF within one to 2 years. The recent OTA assessment of U.S. gas[42] projects a broad year-2000 plausible production range of 9 to 19 TCF; the higher value corresponds to a growth rate, from 1982, of 0.33% p.a. Most other production estimates[42] for 2000 are in the range of 11-15 TCF. AGA's estimates of domestic gas availability[43] are higher: 17 to 26.7 TCF (year 2000), of which the lower-48 supply is expected to be 12 to 19 TCF/year.

As for oil, it may take some time before supply and demand for domestic gas balance.

---

*There was some indication that by the end of CY 1984, this ratio had declined to about 1.18.

4.3. METHANOL

For this woulld-be fuel, a global excess capacity also exists, as reported recently.[44] At the end of 1982, the ratio of production capacity to consumption rate was (14.5×10^6 TPY/11×10^6 TPY), or 1.32. This ratio is projected to increase, at end-1986, to (23.3×10^6 TPY/15×10^6 TPY), or 1.55. In North America, methanol production capacity has increased[60] by 56% since 1980 (largely from inexpensive natural gas in western Canada) to 2.5×10^9 gpy, and demand is 60% of supply - i.e., S/D = 1.67. A separate study[45] by Trichem, Ltd., of London forecasts exports of methanol from all the oil- and gas-producing countries in the Mideast and North Africa to increase from a 1980 level of 0.3 million metric TPY to 1.8 million metric TPY in 1990, representing a growth rate of 19.6% p.a. It appears that a very rapid growth of methanol use for fuel would be required to balance supply and demand by the end of this decade. The current surpluses of oil and gas are counterforces to such a trend, however.

It is noted in passing that an excess production capacity also exists for coal. For the U.S., the National Coal Assoc. estimated[61] a production overcapacity (end-1983) of ~200×10^6 TPY - i.e., S/D = (980×10^6 TPY/780×10^6 TPY) = 1.26. E. B. Leisenring, chairman of Westmoreland Coal Co., has projected[62] a worldwide coal glut through the 1980s and a growth in U.S. coal consumption for electricity generation of 2.5% p.a. For uranium, also, the large global excess supply will likely take years to diminish to the level of world demand.

The outcome of inter-fuel competition will depend primarily on relative future prices - prices which in the short to intermediate terms appear likely to decline.

5. THE OUTLOOK FOR THE DEVELOPING NATIONS

Because of the complex interplay of many interactive factors, and the considerable diversity of the nations involved, the range of projections and opinions concerning the energy/economic future of the developing nations (the less developed countries (LDCs), the Third World) is broad. For much of this sector, a major problem will be burgeoning

populations. IIASA's estimates[24,26] of population growth rates (1980-2000) are illustrative:

Region or Sector	Population Growth, % p.a.
World	1.75
U.S.A	0.92
OECD	0.60
EEC	0.21
LA*	2.39
Af/SEA*	2.33
ME/NAf*	2.51

Regional differences in population growth are placed in striking perspective by recent estimates from the Population Council.[63] It states that from 1960-1980, the number of people aged 20 to 40 increased by 360 million in the developing world and by 60 million in the developed world — a sixfold difference. But from 1980-2000, the relative increase is expected to be 30-fold, based on increases in the number of young adults of 600 million and 20 million, respectively.

One of the relatively sanguine forecasts is Lichtblau's,[29,30] which assumes a real GNP growth for the LDCs (1982-2000) of 4.25% p.a. and projects a growth of total energy consumption at least as high. This study foresees nuclear power in this sector growing sharply, but from a low current base, and contributing ~6.7% of electrical generation in 2000. A greater market share is prevented by capital constraints and inadequate technological infrastructures. With regard to total power demand, H. Laue, Director of IAEA's Division of Nuclear Power, thinks it could increase by fourfold by 2000 (8.5% p.a.).[46] It is noted that the total electrical energy production in the 158 developing nations considered[46] is ~50% of U.S. generation, and that 63% of this power is developed in only 7 countries and 37% in the other 151. It is difficult for the writer to envision this sector increasing its power generation from half that of the U.S. to double the current U.S. level in only 17 years.

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*LA = Latin America; Af/SEA = sub-Sahara Africa excluding South Africa + South and Southeast Asia; ME/NAf = Middle East and North Africa.

My own view is significantly less optimistic. A central point often overlooked in simple extrapolatory projections is that many markets in the industrial world are at or near saturation, and that LDC accessibility to credit markets is contracting. These nations have large potential markets of all kinds - including, e.g., small (~300 MWe) nuclear power reactors - but development of these markets would require immense expenditures corresponding to large increases of already very high levels of external debt. The World Bank, in a study[39] titled "The Energy Transition in Developing Countries," estimates that these nations would need to invest $1.3 trillion over the next decade to adjust to (presently) high energy prices. The study also indicates that the net oil imports of the oil-importing developing countries will continue to grow, at a rate of 1.8% p.a. (1980-1995). The report states that in most of the 18 countries for which the Bank has completed energy assessments, "it is estimated that the consumption of woodfuels is greatly outstripping sustainable production, sometimes by a factor of three or four." Alcock[23] concludes that the period of slow growth and stagnation in energy consumption that his analysis projects (see prior description) will be accompanied by massive hardship, including starvation, in the poorer nations, and that "the satisfaction of third world needs cannot be met simply by an increase in world GNP." Leontief has recently discussed[47] another factor which could operate to the detriment of the LDCs:

> "When a choice between different industries is made, the comparatively low wage levels prevailing in the less developed countries obviously favor labor-intensive industries (simple textiles offer a good traditional example); and the more labor-intensive the industry is, the greater will be the less developed "low-wage" countries' competitive advantage. These conditions are, however, being radically changed by the energence of new technology that, as we have seen, tends to diminish the role of labor, skilled or unskilled, as the most important factor of production and, consequently, as the major component of total costs. As the wage costs - as compared with the cost of other inputs such as raw material, power, and in particular machines and the interest charges on the investment in them — become less important, the competitive advantage enjoyed by the low-wage countries necessarily diminishes.

> In the case of fully automated installations, it becomes nil. Production of textiles, particularly of the simpler kind such as grey cloth, shifted in the past from the developed to the low-wage, less developed countries; but there are signs that, with the introduction of highly automated equipment, this process has been arrested and is even being reversed."

Nussbaum goes so far as to state in his recent book[48] that of the Third World nations, only a half dozen — probably Brazil, South Korea, Taiwan, Hong Kong, Israel, and Singapore — will "be able to make it to the twenty-first century" - i.e., to succeed in smoothly making the transition. Little hint is given as to how Red China, e.g., might be expected to react in the circumstances described.

Looking over this possibly deep valley (low plain?) to the post-2000 period, the CAL projection[3] is for a very large increase in primary energy consumption from 2000 to 2025: a growth for the U.S. of ~73 quads (2.8% p.a.) and a world growth of ~676 quads (4.1% p.a.) — an increment over ninefold greater than that for the U.S. This growth level may be compared with current world consumption rates of 105 quads/year of oil and 60 quads/year of natural gas. If this projection is credible, the coming fifteen years would best be used to develop energy technologies that could be deployed throughout the world during the subject period to meet the large energy demands that would then materialize.

6. ECONOMIC IMPLICATIONS

Viewed collectively, most available energy projections either assume or forecast a relatively narrow range of real energy price trajectories over the next decade. For oil, e.g., for which more estimates have been published than for any fuel, virtually all conventional price change estimates encompass a range from slightly less to slightly more than the rate of general price inflation. The relative rates of change in the real prices of competing energy forms will naturally influence, and rather directly, future changes in their consumption rates.

Among the more interesting — and possibly more accurate — estimates are those of lower real oil prices (in 1982 U.S. dollars) in coming

years. These include[40] DOE's, from its recent annual energy outlook, which projects a minimum of $21/bbl by 1985, and Steffes' value of $20/bbl by 1989. More drastic declines are projected by Pylant[40] (about $16/bbl by 1995) and by Marchetti[9,18] ($12/bbl "during the next few years," interpreted by the writer to mean in the early 1990s). The latter estimate[18] is of particular interest and of potential importance because it is based on the empirical observation that since 1800, real energy prices have spiked upward or "flared" in close time proximity to a primary energy form attaining its maximum market share. The last (fourth) such peak (for both real price and market share) was presumably in 1980-81 for world oil. This pattern projects the next peak to be for world natural gas in 2025 ($\pm$10 years).

In the limited time available, no projections of real GWP were made. Data from the Worldwatch Institute[64] indicate the growth in real GWP from 1950-1983 averaged 4.3% p.a.; the real GWP per capita over the same 33-year interval increased at a rate of 2.5% p.a. By either measure, a secular decline has occurred, and the change in real GWP per capita for the period 1979-1983 was nil.

For the U.S., projections of real GNP growth differ widely. Conventional assumptions for 1982-2000 tend to cluster at a relatively high level, as exemplified by the rates used by the U.S. Department of Commerce[33] (2.8% p.a.), by the GRI[49] (2.9% p.a.), and by Lichtblau[29] (2.5% p.a.). These rates imply a growth of real GNP per capita of about 1.6% to 2.0% p.a., bracketing the historical (1885-1970) U.S. average of 1.81% p.a. Lower rates are anticipated, among others, by Steffes,[40] who expects the period 1983-1989 to be characterized by alternating economic recoveries and recessions and an average real GNP growth rate of 1.0% p.a. At the same (lower) end of the spectrum of estimates are those of Stewart,[4] who appears to differ from the others cited in that he presents and uses an acceptable rationale for projecting real GNP growth rather than, in essence, assuming a value. This approach simply combines the CAL estimates of future total energy (E_t) consumption rates (previously described) with two trends for the ratio of real GNP to total energy to project the future course of real GNP. Figure 4 depicts

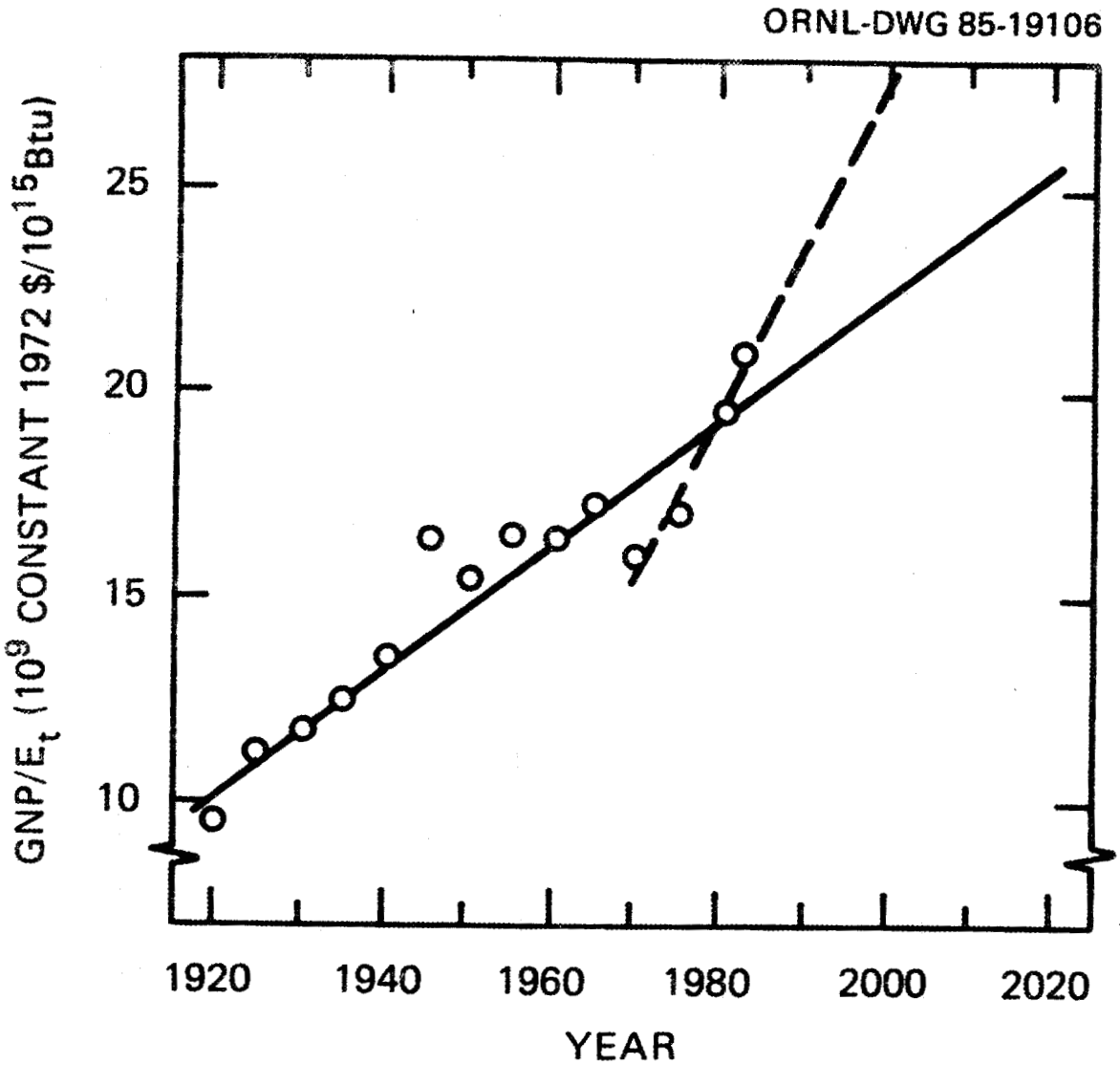

Figure 4. Historical trend in the U.S. ratio of GNP/E_t. The dashed line illustrates a new trend assuming a step improvement beginning 1970.

the historical trend in the (GNP/E_t) ratio, with GNP in constant 1972 dollars, from 1920 to 1982, with a linear projection to 2020. It is first assumed that the (GNP/E_t) curve will follow the long-term (low slope) trend. If this eventuates, the real GNP growth for the U.S. (1980-1990) will average 0% p.a. As an alternative, it is assumed that the (GNP/E_t) ratio will continue to increase at the higher rate characteristic of the shorter-term trend from 1970 to 1982. This assumption gives an average real GNP growth for the 1980s of ~1.3% p.a. I think this projection is the most conceptually satisfactory, for the short term, of the dozens that have been published. The probable degree of partitioning of this relatively low economic growth rate between the civilian and military sectors is perhaps a matter better addressed in a separate study, as are the many associated implications for employment rates.

We conclude with Table 2, which compares per-capita primary energy consumption rates in 1980 (part A) with various projections made in 1981 for the year 2030 (part B). Considering the time interval involved, the projections are in reasonable agreement.

7. SUMMATION

The provisional global energy projection for the coming decade is one of low growth rates accompanied by economic adjustments and difficulties and falling energy prices. The projection for the first quarter of the twenty-first century reflects a cyclic reversal to sharply increased economic activity, energy demands, fuel prices, and pressure on the technological sector to provide an adequate energy supply.

Table 2. Unit Primary Energy Consumption Rates

A. Per-Capita Primary Energy Consumption (1980)

	kWt year/capita year[a]
• United States[b]	11
• North America	8
• Western Europe	5
• World	2
• LDCs	0.5
• Pakistan	0.25

B. 1981 Projections for the Year 2030

	U.S.	N.A.	World	Reference No.
• H. B. Stewart (CAL)[c]	17.6	-	5.4	3
• IIASA - High Scenario	-	18.6	4.5	26
• IIASA - Low Scenario	-	13.4	3.0	26
• IIASA - Minimum Scenario	-	8.0	2.0	26
• ONEP - High[d]	18.8	-	-	51
• ONEP - Low[d]	16.0	-	-	51

C. Stewart, Saturated Asymptotes (~2100)

	19-23	-	9.0	3, 4

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[a]The energy units in Parts B and C are also kWt year/capita year.
[b]Other values for the U.S.:

1875 (minimum for 1850 ff.)	- 3.2	Ref. 52
1920 (maximum prior to 1942)	- 6.7	Ref. 52
1935 (Depression minimum)	- 5.3	Ref. 52
1970	- 11.3	Ref. 52
1975	- 12.0	
1981	- 10.8	
1982 (lowest since 1967)	- 10.2	
1983	- 10.1	

[c]5-year extrapolation.
[d]10-year extrapolation.

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