INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR.704 - 30

Workshop on Materials Science and Physics of Non-Conventional Energy Sources

(30 August - 17 September 1993)

"Energy for a Sustainable World"

Thomas B. Johansson
Lund University
Institute of Technology
Environmental/Energy Systems Study
Gerdagatan 13
S-223 62 Lund
Sweden

These are preliminary lecture notes, intended only for distribution to participants.

WORLD ENERGY CONF.
(1989.)

PROJECTIONS FOR 2020

*

GDP 3%/yr

ENERGY 1.6 %/yr ⇒ +75%

NUCLEAR 4 → 8 % ; +340 %

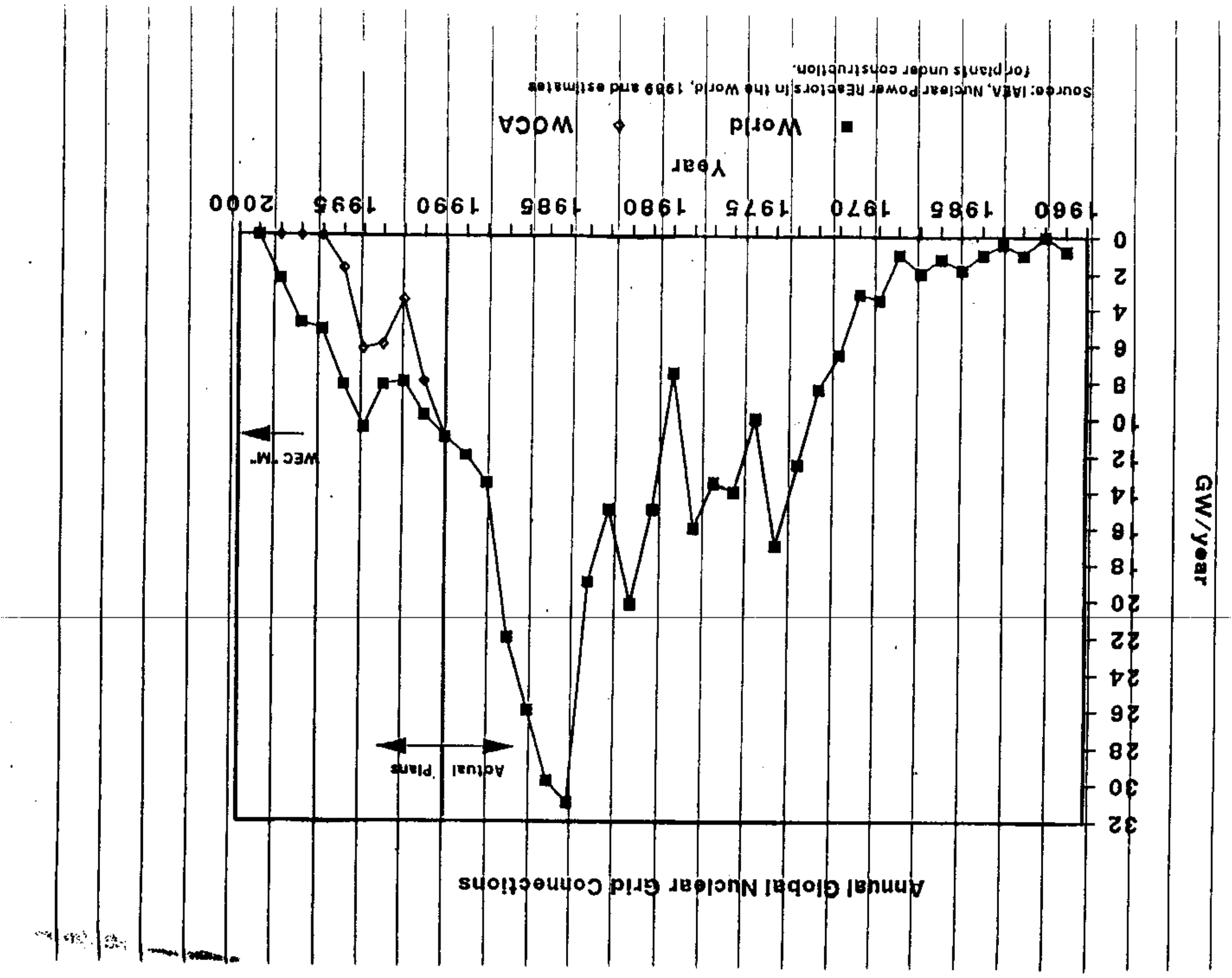
RENEWABLE 6 → 8%

REST: FOSSIL FUELS

CO_2 + 70 % (IPCC: −60% or

Diversion - Resistance Criteria

1. Restrictions non-discriminatory among states
2. No weapons-useable material outside international centers
3. Minimum weapons-useable material produced
4. Spent fuel stored and disposed of in international centers
5. Reactors under national authority to produce less than one critical mass per GWyr



THE NUCLEAR WEAPONS LINK TO NUCLEAR POWER

- AT HIGH LEVELS OF NUCLEAR POWER DEVELOPMENT, URANIUM SUPPLY CONSTRAINTS DICTATE A SHIFT TO:

  NUCLEAR FUEL REPROCESSING
  RECYCLE OF PLUTONIUM IN FRESH REACTOR FUEL
  A SHIFT TO PLUTONIUM BREEDER REACTORS

- ENORMOUS QUANTITITIES OF SEPARATED PLUTONIUM WOULD CIRCULATE IN COMMERCE WORLDWIDE

- THE 1981 IIASA STUDY PROJECTED THAT NUCLEAR POWER WOULD GROW AS FOLLOWS:

1986	260 GW
2030	2600 TO 4400 GW

- THE IIASA NUCLEAR SCENARIOS IMPLY THAT THE AMOUNT OF PLUTONIUM DISCHARGED ANNUALLY FROM POWER PLANTS IN SPENT FUEL, REPROCESSED, AND RECYCLED IN FRESH FUEL WOULD BE:

  2,600,000 TO 4,100,000 KG PER YEAR.

- LESS THAN 10 KG OF PLUTONIUM IS NEEDED TO MAKE A NUCLEAR WEAPON

OLJA

(Gton, 1991)

	Reserver	Produktion	Konsumtion	R/P
Nord-Amerika	5.3	.519	.849	10.2
Latin Amerika	16.9	.395	.252	43.1
OECD Europa	1.9	.215	.631	9.0
Non-OECD Europa	8.0	.530	.487	15.1
Mellanöstern	89.4	.821	.153	>100
Afrika	8.0	.330	.097	24.5
Asien&Australien	5.9	.322	.671	18.3
(Japan	--	--	.247	--)
Världen	**135**	**3.13**	**3.14**	**43.4**

Källa: BP 1992.

LDC CAPITAL NEEDS

for energy supply expansion

a.	1970-80	5.1	5.9		1-2 (70) 2-3 (80)
b.	80-95	4.8	4.5	130	4
c.	80-00	3.5	2.5	123	3.6
d.	80-00	4.5	4.7	222	6.0

b. World Bank, 1983

c. World Energy Conference, low proj., 1987

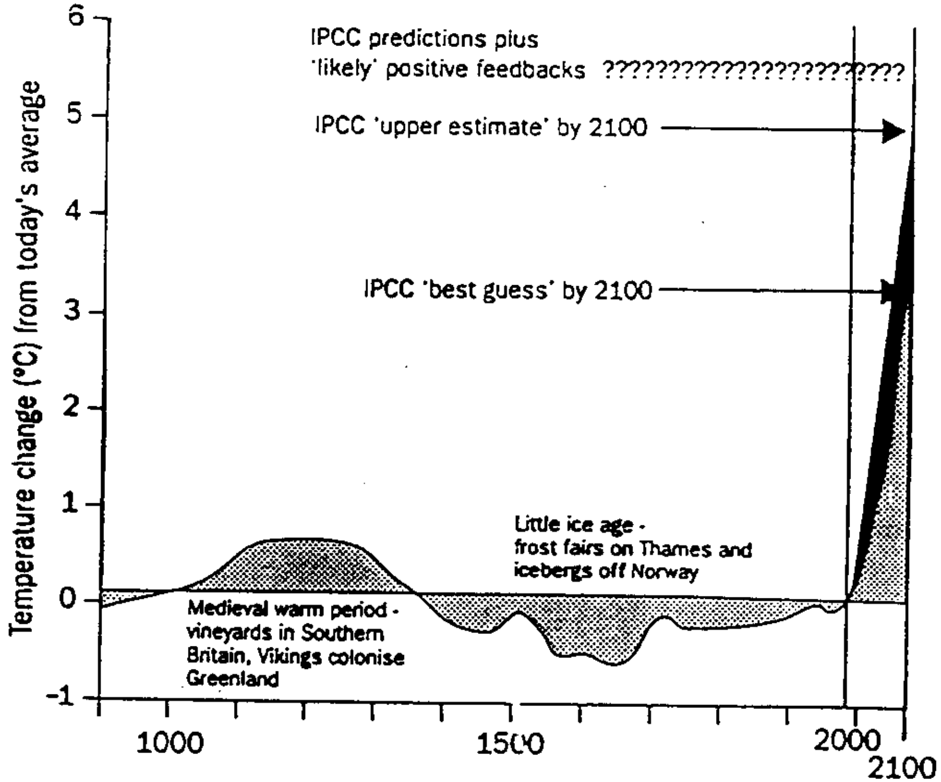
d. World Energy Conference, high proj., 1987

Investments

~100 G$/yr power sector

10-80% of foreign exchange earnings

10-70% of debt



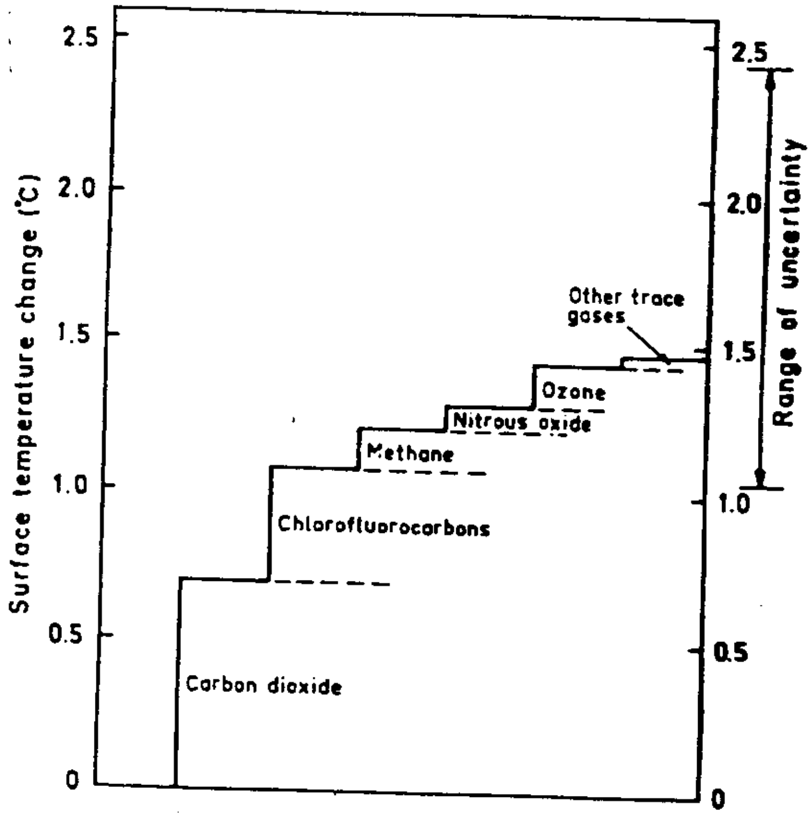


Figure 1.3 Cumulative equilibrium surface temperature warming due to increase in carbon dioxide and other trace gases from *AD* 1980 to 2030 as computed by a one-dimentional model. (After Ramanathan *et al.*, 1985.) Due to feedback mechanisms as revealed by general circulation models (cf. sub-section 4.4.3 and Chapter 5) expected changes are 0.8–2.6 times the values given in this figure

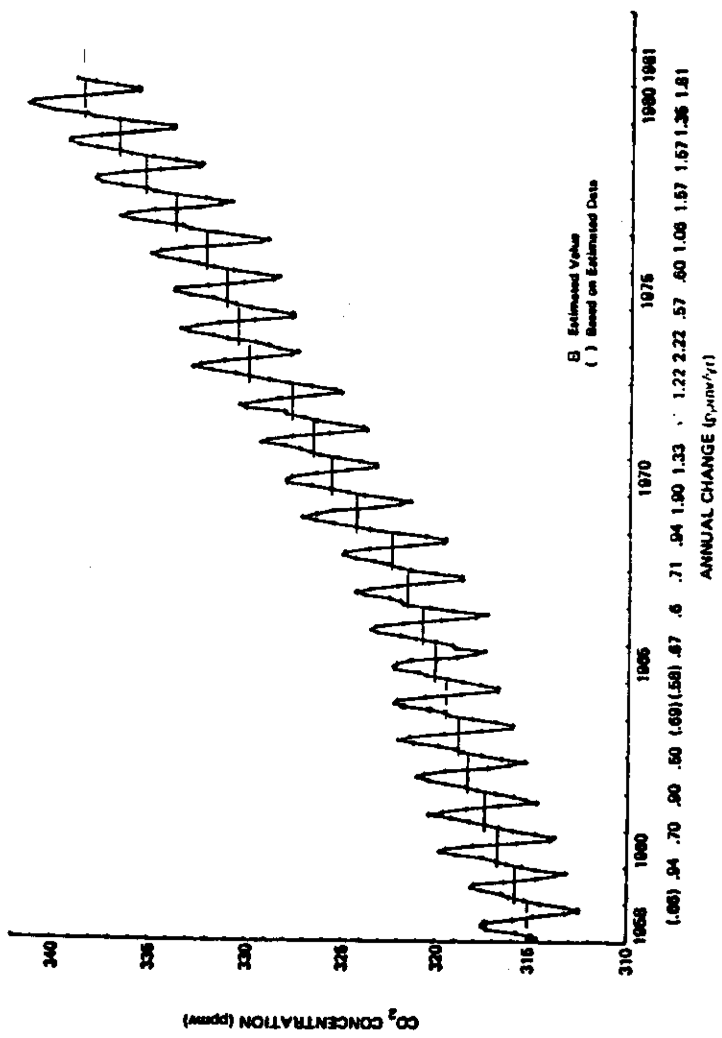


FIGURE 1.2 Mean monthly concentrations of atmospheric CO_2 at Mauna Loa. The yearly oscillation is explained mainly by the annual cycle of photosynthesis and respiration of plants in the northern hemisphere. See Section 1.2.2 for discussion of annual cycle. (Source: Geophysical Monitoring for Climate Change, National Oceanic and Atmospheric Administration.)

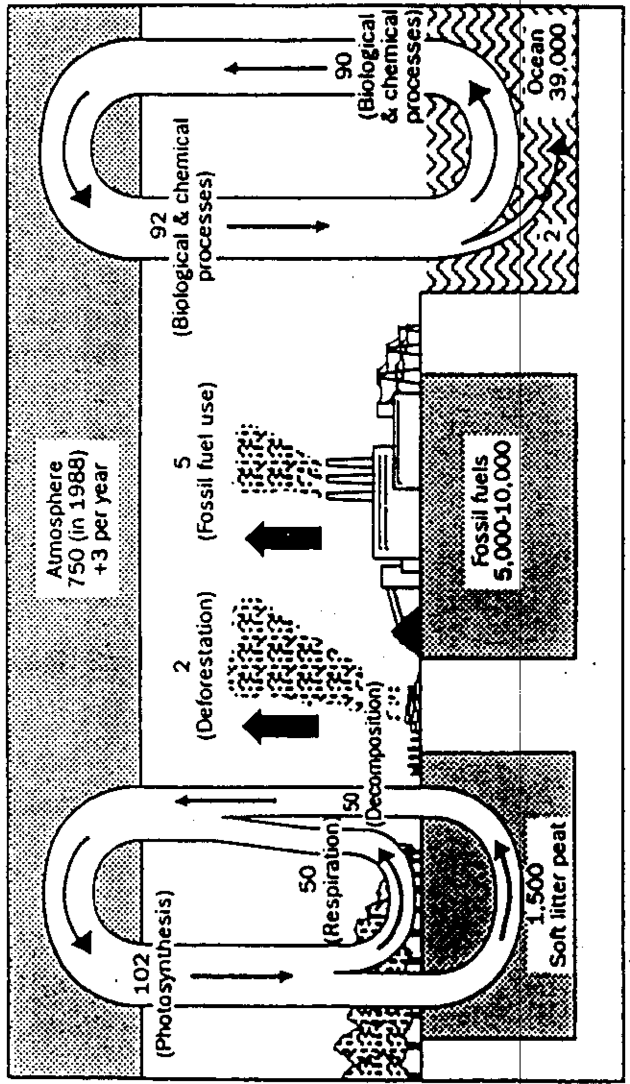


Fig. 1.3. Generalized portrayal of the carbon cycle, showing main reservoirs and fluxes. ***Quantities of carbon are in Gt (reservoirs) and Gt per annum (fluxes). Estimates are from IPCC, Scientific Assessment of Climate Change, fig. 1.1, and references therein. The figure is based on Stephen Schneider's drawing in Scientific American, Dec. 1989.***

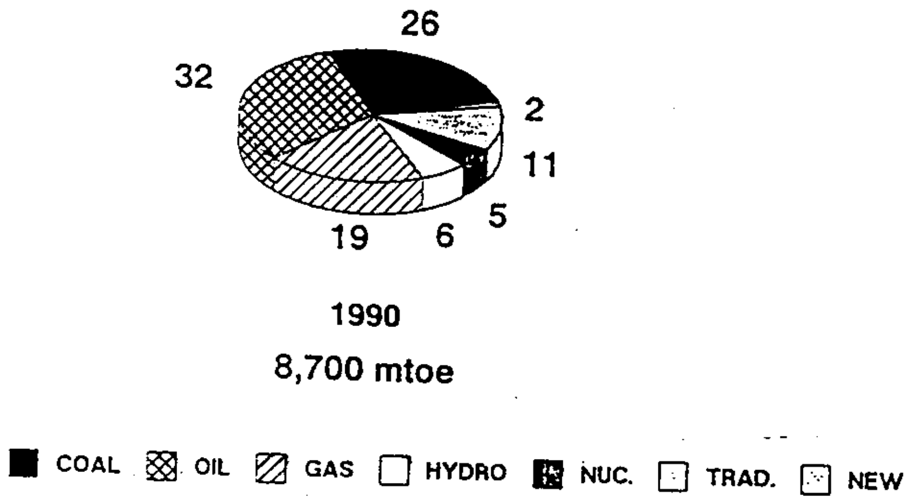
Residential air pollution

Desertification

Urban air pollution

Acidification

Climate Change


26
32
2
11
5
6
19
1990
8,700 mtoe
COAL
OIL
GAS
HYDRO
NUC.
TRAD.
NEW

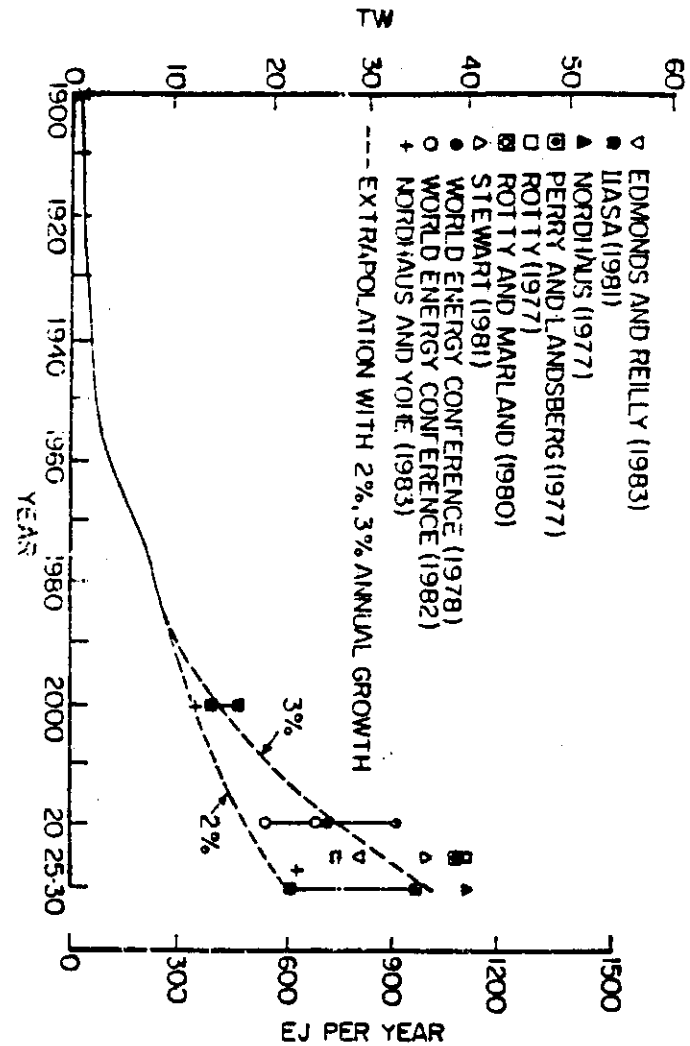

TW
EJ PER YEAR
YEAR
EDMONDS AND REILLY (1983)
IIASA (1981)
NORDHAUS (1977)
PERRY AND LANDSBERG (1977)
ROTTY (1977)
ROTTY AND MARLAND (1980)
STEWART (1981)
WORLD ENERGY CONFERENCE (1978)
WORLD ENERGY CONFERENCE (1982)
NORDHAUS AND YOHE (1983)
EXTRAPOLATION WITH 2%, 3% ANNUAL GROWTH
3%
2%

Figure 1

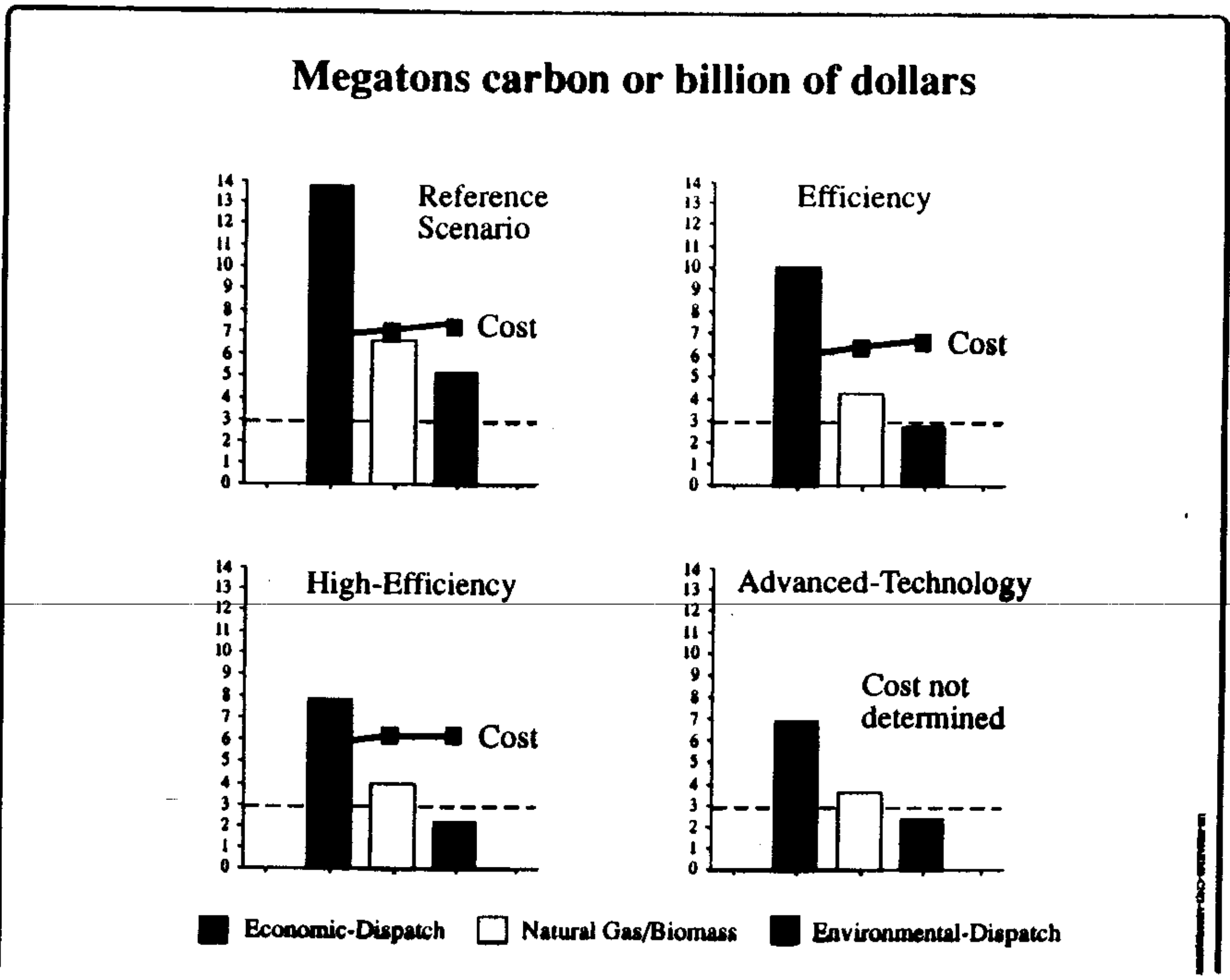


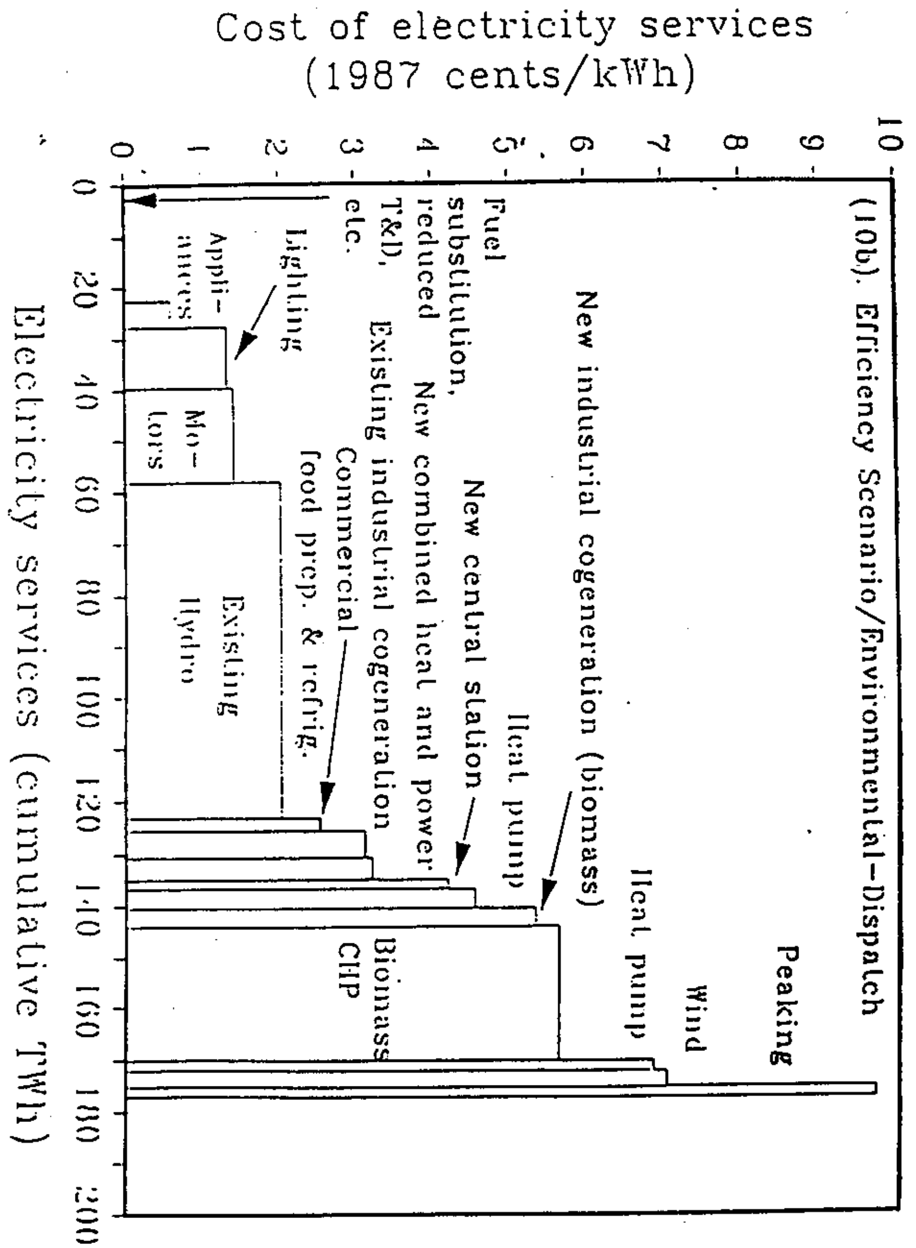
Table 4. Total annualized costs for all 194 TWh_{eq} electric energy services (generating capacity, efficient end-use technology, and fuel switching).[a]

(cents/kWh_{eq})		<—— Demand Scenario			——>
Supply Scenario	1987	Reference Scenario	Efficiency Scenario	High-Efficiency Scenario	Advanced-Technology Scenario
Electric energy services (TWh_{eq})[b]		194	194	194	194
of which electricity supply (TWh_{e})	129	140	111	96	88
Economic-Dispatch	2.8[c]	2.6	2.3	2.1	---
Natural Gas/Biomass		2.7	2.4	2.3	---
Environmental-Dispatch		2.9	2.6	2.3	---

a All costs for supply and demand-side investments are calculated using the same 6% real discount rate.

b Excludes 53 TWh of process heat and district heating in each case.

c Joint Council of the Swedish Electric Power Producers (Kraftsam) estimate.



TWO ELECTRICITY SYSTEMS FOR 2010 (TWh)

	REFERENCE/ ECONOMIC DISPATCH	HIGH-EFFICIENCY/ ENVIRONMENTAL DISPATCH
EXISTING CAPACITY		
Hydro	65	65
Co-gen.	6.5	0
Oil	1	1
Peaking gas turbines	1	1
Ind. co-gen.	5	5
NEW CAPACITY		
Ind. co-gen. bio	0	3.5
FB Coal	5.3	0
STIG Ng	5.3	0
STIG Bio	0	17.4
Coal central st.	25.2	0
Nat. gas comb. cyc.	25.2	0
Wind	0	3
TOTAL	139.5	95.9
FUEL USE:		
Coal	96	0
Oil	17	11
Gas	86	23
Biomass	0	84
TOTAL FUELS	199	118

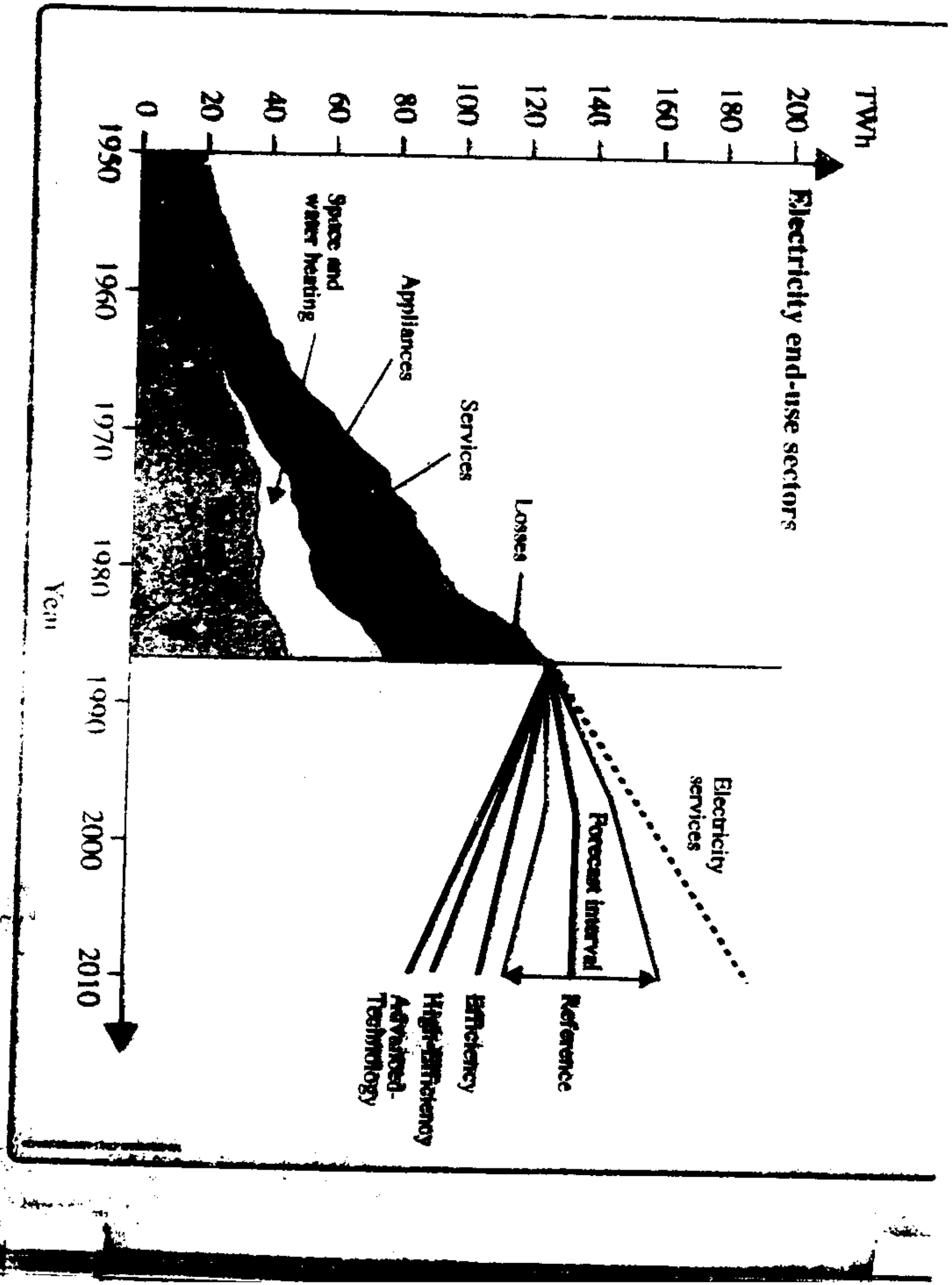
ELECTRICITY SUPPLY SCENARIOS

1) ECONOMIC DISPATCH
   50% coal, 50% natural gas

2) NATURAL GAS/BIOMASS (< 50 TWh)

3) ENVIRONMENTAL DISPATCH
   ≤ 90 TWh biomass + some natural gas

SYSTEM BOUNDARY:
All 1987 electricity uses + heat for district heating and from industrial co-generation



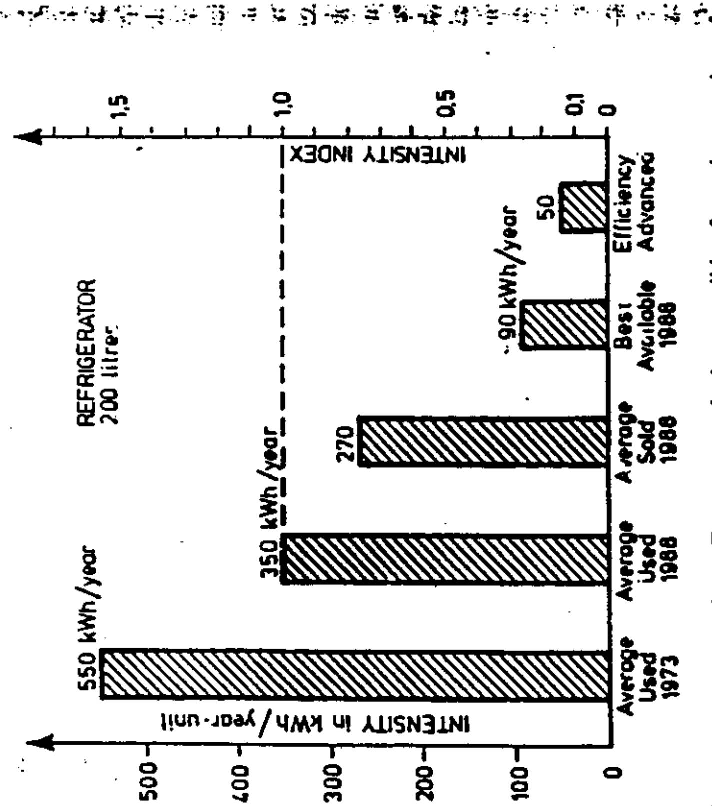


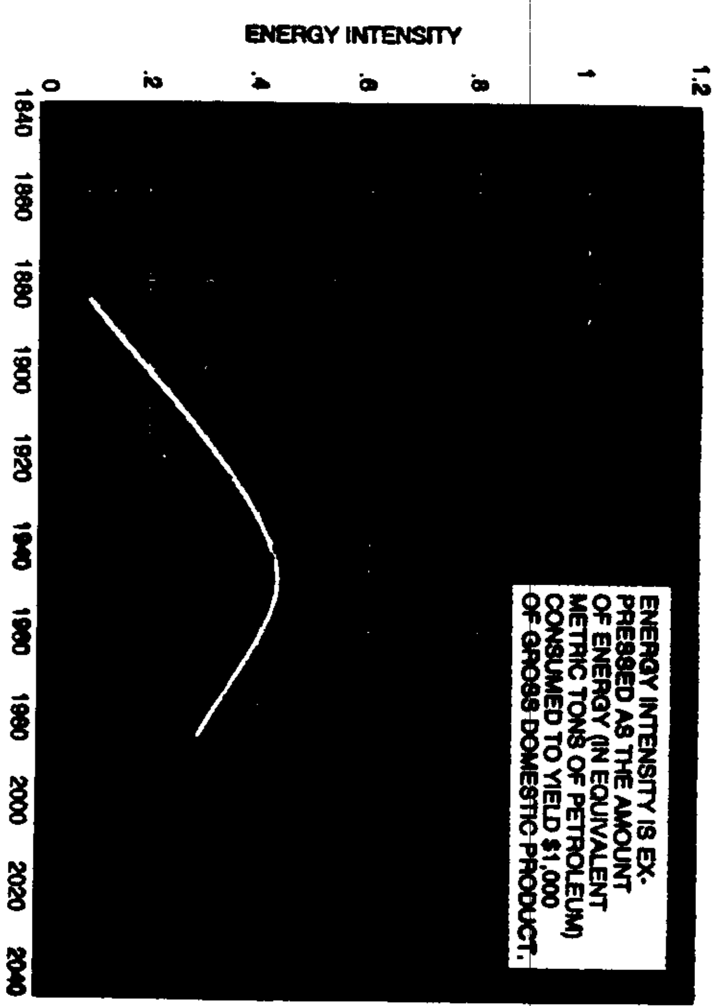
Figure 1: Electricity consumption at European standard test condition for various versions of a 200 litre refrigerator with no freezer compartment. The intensity index on the scale to the right illustrates the relative improvements, and it is approximately transferable to other refrigerators as well as to units with a small freezer compartment and to commercial units in shops, etc.

ELECTRICITY DEMAND SCENARIOS

General assumption: +1.9%/yr in GDP
+2.6%/yr industrial output

1) REFERENCE	Business-as-usual electricity price + 50%
2) EFFICIENCY	Cost effective as compared to new supply with 6% real interest;
3) HIGH-EFFICIENCY	no taxes
4) ADVANCED TECHNOLOGY	

All end-use technologies are assumed to be introduced at the rate of capital turn-over and expansion



A THOUGHT-EXPERIMENT.

$$E_{TOT} = \sum (\text{ACTIVITY}) * (\text{SPECIFIC ENERGY})$$

ASSUME:

(ACTIVITY) ≡ WEST EUROPE 1970's

E.G. 320 kg of steel per cap.

(SPECIFIC ENERGY) ≡ ENERGY EFFICIENT END-USE TECHNOLOGY. (COMM. OR NEAR COMM)

E.G. ELRED/PLASMASMELT @ 10 GJ/tonne

⇒ 1 kW per capita

Table 4. Final energy use scenario for a developing country in a warm climate, with amenities (except for space heating) comparable to those in the WE/JANZ[a] region in the 1970s, but with currently best available or advanced energy utilization technologies.

	Average Rate of Energy Use (Watts per Capita)		
Activity	Electricity	Fuel	Total
Residential			
Cooking		34	
Hot Water	29		
Refrigeration	14		
Lights	4		
TV	3		
Clothes Washer	2		
Subtotal	51	34	85
Commercial	22	–	22
Transportation			
Automobiles		107	
Intercity Bus		26	
Passenger Train	5	32	
Urban Mass Transit	2	8	
Air Travel		21	
Truck Freight		32	
Rail Freight	5		
Water Freight (incl. bunkers)		50	
Subtotal	12	276	288
Manufacturing			
Raw Steel	28	77	
Cement	6	54	
Primary Aluminum	11	26	
Paper and Paperboard	11	24	
Nitrogenous Fertilizer	–	36	
Other[b]	65	212	
Subtotal[c]	121	429	550
Agriculture	4	41	45
Mining, Construction	–	59	59
TOTALS	210	839	1049

Notes
[a] Here WE/JANZ stands for Western Europe, Japan, Australia, New Zealand, and South Africa. For the activity levels indicated in Table 2 and the energy intensities given in Table 3.
[b] This is the residual.
[c] It has been estimated that at Sweden's 1975 level of GDP, final energy demand in manufacturing would have been 1.0 kW (half the actual value), had advanced technology been used (17). The value assumed here is 45% less, since the average per capita GDP was 45% less for W. Europe than for Sweden in 1975. Also, 22% of final manufacturing energy use is assumed to be electricity, the Swedish value for 1975.

... Technological opportunities for a developing country in a warm climate to use currently best available or advanced energy utilization technologies.

Activity	Technology, Performance
Residential	
Cooking	70% efficient gas stove[a]
Hot Water	heat pump WH, COP = 2.5[b]
Refrigeration	Electrolux Refrigerator/Freezer, 475 kWh/year[c]
Lights	Compact Fluorescent Bulbs[c]
TV	75 Watt unit
Clothes Washer	0.2 kWh/cycle[d]
Commercial	Performance of Härnösand Building (all uses, ex. space heating)[e]
Transportation	
Automobiles	Cummins/NASA Lewis Car at 3.0 l/100 km[c]
Intercity Bus	3/4 energy intensity in '75[f]
Passenger Train	3/4 energy intensity in '75[g]
Urban Mass Transit	3/4 energy intensity in '75[h]
Air Travel	1/2 US energy intensity in '80[i]
Truck Freight	0.87 MJ/ton (t)-km[j]
Rail Freight	Electric rail at 0.18 MJ/t-km[k]
Water Freight	60% of OECD energy intensity[l]
Manufacturing	
Raw Steel	Av. Plasmasmelt & Elred Processes[c]
Cement	Swedish ave in 1983[m]
Primary Aluminum	Alcoa process[n]
Paper and Paperboard	Av of 1977 Swedish designs[o]
Nitrogenous Fertilizer	Ammonia derived from methane[p]
Agriculture	3/4 of WE/JANZ energy intensity[q]
Mining, Construction	3/4 of WE/JANZ energy intensity[q]

Notes
[a] Compared to an assumed 50% efficiency for existing gas stoves. 70% efficient stoves having low NO_x emissions, have been developed by Thermoelectron Corporation for the Gas Research Institute in the United States (36).
[b] The assumed heat pump performance is comparable to that of the most efficient heat pump water heaters available in the US in 1982 (37).
[c] See text.
[d] Typical value for US washing machines.
[e] The Härnösand Building was the most energy-efficient commercial building in Sweden in 1981, at the time it was built. It used 0.13 GJ of electricity per square meter of floor area for all purposes other than space heating (18).
[f] A 25-percent reduction in energy intensity is assumed relative to the 1975 average of 0.60 MJ/p-km for intercity buses, owing to the introduction of adiabatic diesels with turbo-compounding.
[g] A 25-percent reduction in energy intensity is assumed relative to the 1975 average of 0.60 (0.20) MJ/passenger (p)-km for diesel (electric) passenger trains, owing to the introduction of adiabatic diesels with turbo-compounding (electric motor control technology).
[h] A 25-percent reduction in energy intensity is assumed relative to the 1975 average of 1.13 (0.41) MJ/p-km for diesel buses (electric mass transit), owing to the introduction of adiabatic diesels with turbo-compounding (electric motor control technology).
[i] A 50-percent reduction in energy intensity is assumed relative to the 1980 US average value of 3.8 MJ/p-km for air passenger travel, owing to various improvements (38).
[j] The assumed energy intensity is 1/3 less than the simple average today in Sweden for single unit trucks (1.28 MJ per ton-km) and combination trucks (0.76 MJ per ton-km), to take into account improvements via use of adiabatic diesels with turbo-compounding.
[k] The average energy intensity for electric rail in Sweden, with an average load of 300 tons and an average load factor of about 40%.
[l] A 40-percent reduction in fuel intensity is assumed, reflecting innovations such as the adiabatic diesel and turbo-compounding.
[m] Assuming an energy intensity of 3.56 GJ of fuel and 0.40 GJ of electricity per ton, the average for Sweden in 1983.
[n] Assuming an energy intensity of 84 GJ per ton of fuel (the US average in 1978) and 36 GJ of electricity—the requirements for the Alcoa process now being developed (39).
[o] Assuming an energy intensity of 7.3 GJ of fuel and 3.2 GJ of electricity per ton, the average for 1977 Swedish designs (17).
[p] Assuming an energy intensity of 44 GJ of fuel per ton of nitrogen in ammonia, the value with steam reforming of natural gas in a new fertilizer plant (40).
[q] Assuming a 25-percent reduction in energy intensity, owing to innovations such as the use of advanced diesel engines.

$$E = \sum_i (\text{activity})_i * (\text{specific energy use})_i$$

Energy services measured in kWh_{eq}

with 1987 as base year

$$E_{eq} = \sum_i (\text{activity})_{i,2010} (\text{specific energy use})_{i,1987}$$

FIVE STEPS of BOTTOM-UP ANALYSIS

1. Determine the energy service level for a target year,
2. Collect data on energy supply and end-use technologies,
3. Establish "supply curves" for energy supply and end-use efficiency improvements, and possible combinations there-of to reach the service level,
4. Analyze the market, institutional, legislative, and regulatory conditions that affect the possible use of different options,
5. Synthetize a strategy to reach the goals,

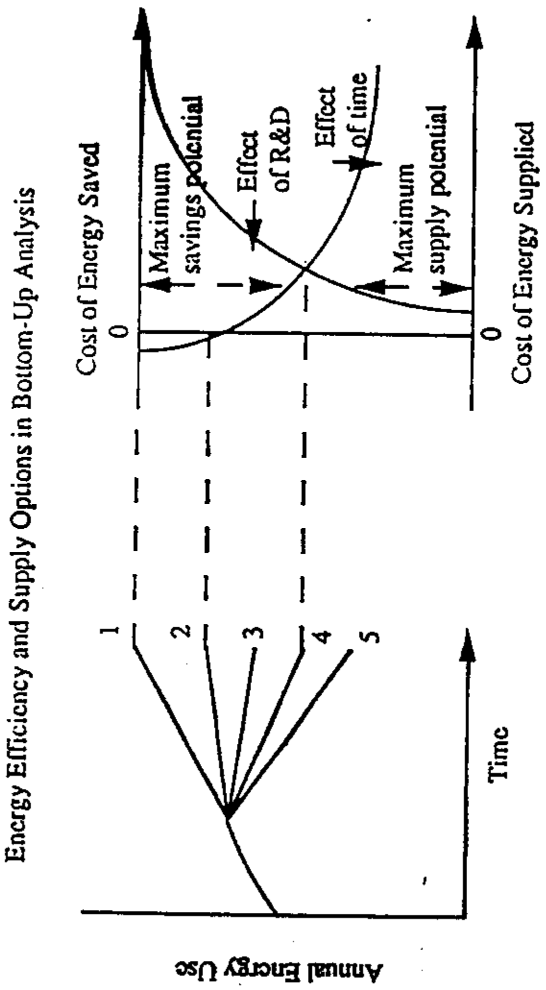


Figure 1. The relationship between bottom-up energy scenarios and marginal costs.

SWEDISH GOALS

ECONOMIC GROWTH

"FULL" EMPLOYMENT

* * *

NUCLEAR PHASE-OUT 2010

NO HYDRO-POWER EXPANSION

NO INCREASE OF CO_2 EMISSIONS

REDUCED OIL IMPORTS

REDUCED SO_x + NO_x EMISSIONS

* * *

ENERGY EFFICIENCY

RENEWABLE ENERGY

Table 2. Activity levels for a hypothetical developing country in a warm climate, with amenities (except for space heating) comparable to those in the WE/JANZ[a] region in the 1970s.

Activity	Activity Level
Residential[b]	4 persons/HH
Cooking	Typical cooking level w/LPG stoves[c]
Hot Water	50 liters of hot water/capita/day[d]
Refrigeration	One 315 liter refrigerator-freezer/HH
Lights	New Jersey (US) level of lighting[e]
TV	1 color TV/HH, 4 hours/day
Clothes Washer	1/HH, 1 cycle/day
Commercial	5.4 m^2 of floor space/capita (WE/JANZ av, '75)
Transportation	
Automobiles	0.19 autos/capita, 15,000 km/auto/year (WE/JANZ av, '75)
Intercity Bus	1850 passenger (p)-km/capita (WE/JANZ av, '75)
Passenger Train	3175 p-km/capita (WE/JANZ av, '75)[f]
Urban Mass Transit	520 p-km/capita (WE/JANZ av, '75)[g]
Air Travel	345 p-km/capita (WE/JANZ av, '75)
Truck Freight	1495 ton (t)-km/capita (WE/JANZ av, '75)
Rail Freight	814 t-km/capita (WE/JANZ av, '75)
Water Freight	1/2 OECD Europe av, '78[h]
Manufacturing	
Raw Steel	320 kg/capita (OECD Europe av, '78)
Cement	479 kg/capita (OECD Europe av, '80)
Primary Aluminum	9.7 kg/capita (OECD Europe av, '80)
Paper and Paperboard	106 kg/capita (OECD Europe av, '79)
Nitrogenous Fertilizer	26 kg N/capita (OECD Europe av, '79/80)
Agriculture	WE/JANZ av, '75
Mining, Construction	WE/JANZ av, '75

Notes

[a] Here WE/JANZ stands for Western Europe, Japan, Australia, New Zealand, and South Africa. The WE/JANZ 1975 average values for activity levels and energy intensities given in this table are from Reference 20.

[b] Activity levels for residences are estimates, owing to poor data for the WE/JANZ region.

[c] Equivalent in terms of heat delivered to the cooking vessels to using one 13 kg canister of LPG/month for a family of 5, corresponding to per-capita fuel consumption rate of 49 Watts.

[d] For water heated from 20 to 50°C.

[e] See text.

[f] In 1975 the diesel/electric mix was in the ratio 70/30.

[g] In 1975 the diesel/electric mix was in the ratio 60/40.

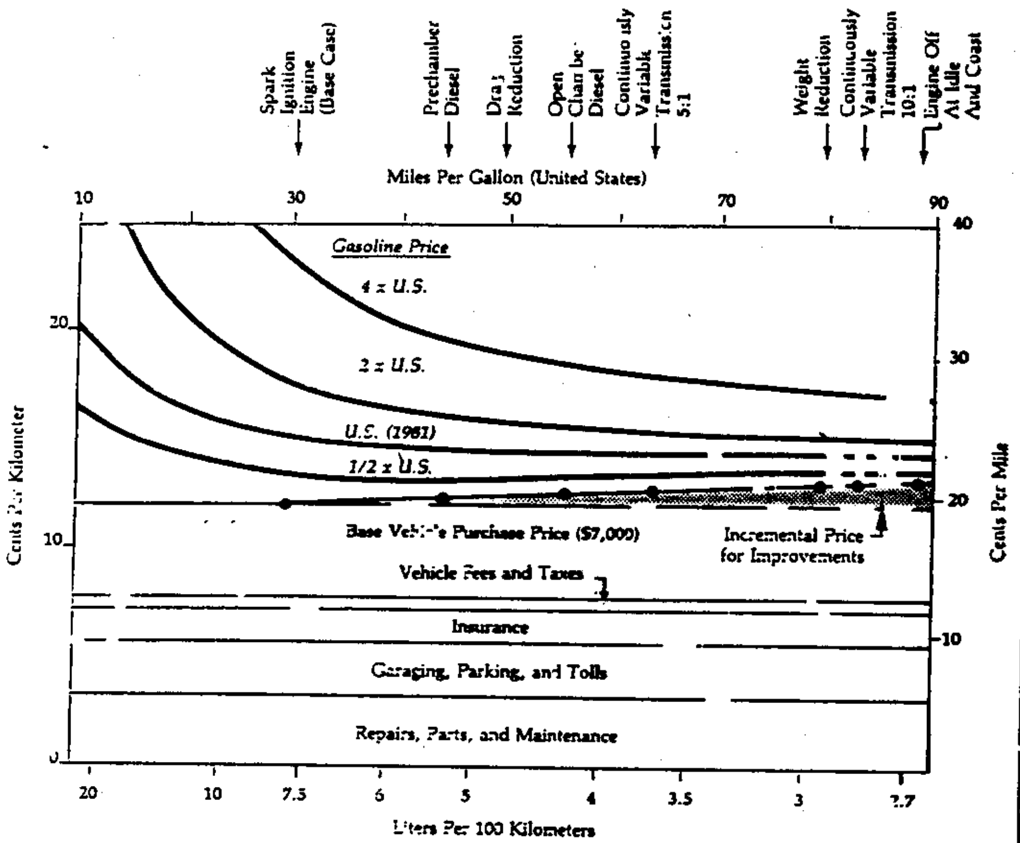
[h] The ton-km per-capita of water freight in 1978 in OECD Europe is assumed to be reduced by half because of reduced oil use (58% of Western European import tonnage and 29% of that of exports were oil in 1977) and emphasis on self reliance.

Cost-Effective Energy Efficiency Potentials

%

	Retrofits	New Investments
Conversion	10-20	10-20
End-Use	10-40	50-90

Figure 19. The Cost of Driving (in United States Cents Per Kilometer and Mile) Versus Automotive Fuel Economy.

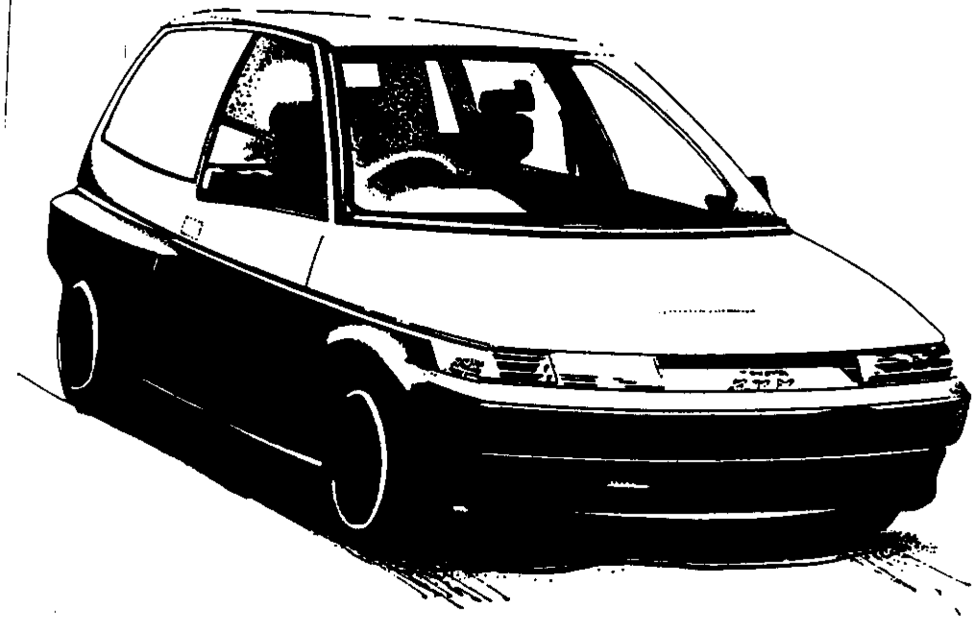


The figure shows that the reduced operating costs associated with fuel economy improvements are roughly offset by the increased capital costs of these improvements, over a wide range of fuel economies.

The indicated energy performance is based on computer simulations of an automobile having various fuel economy improvements added in the sequence shown, at the top of the graph. The base case car is a 1981 Volkswagen Rabbit (gasoline version).

Source: F. von Hippel and B.G. Levi, "Automotive Fuel Efficiency: The Opportunity and Weakness of Existing Market Incentives, *Resources and Conservation*, 1983, vol. 10: 103-124.

Figure 4. The Toyota AXV, a Prototype Four- to Five-Passenger, Super Fuel-Efficient Car



Toyota AXV

Introduced in late 1985, the AXV has a fuel economy of 2.4 lhk (98 mpg) on the combined urban/highway test administered by the U.S. Environmental Protection Agency. For comparison, the average U.S. automobile gets about 12.4 lhk (19 mpg), and the average car in the rest of the world about 9.8 lhk (24 mpg). High fuel economy is achieved with the systematic application of presently available technologies: low weight (650 kg [1,430 lb]) from extensive use of plastics and aluminum, low aerodynamic drag, a direct-injection diesel engine (the kind used in trucks), and a continuously variable transmission.

Source: Toyota press release, October 23, 1985.

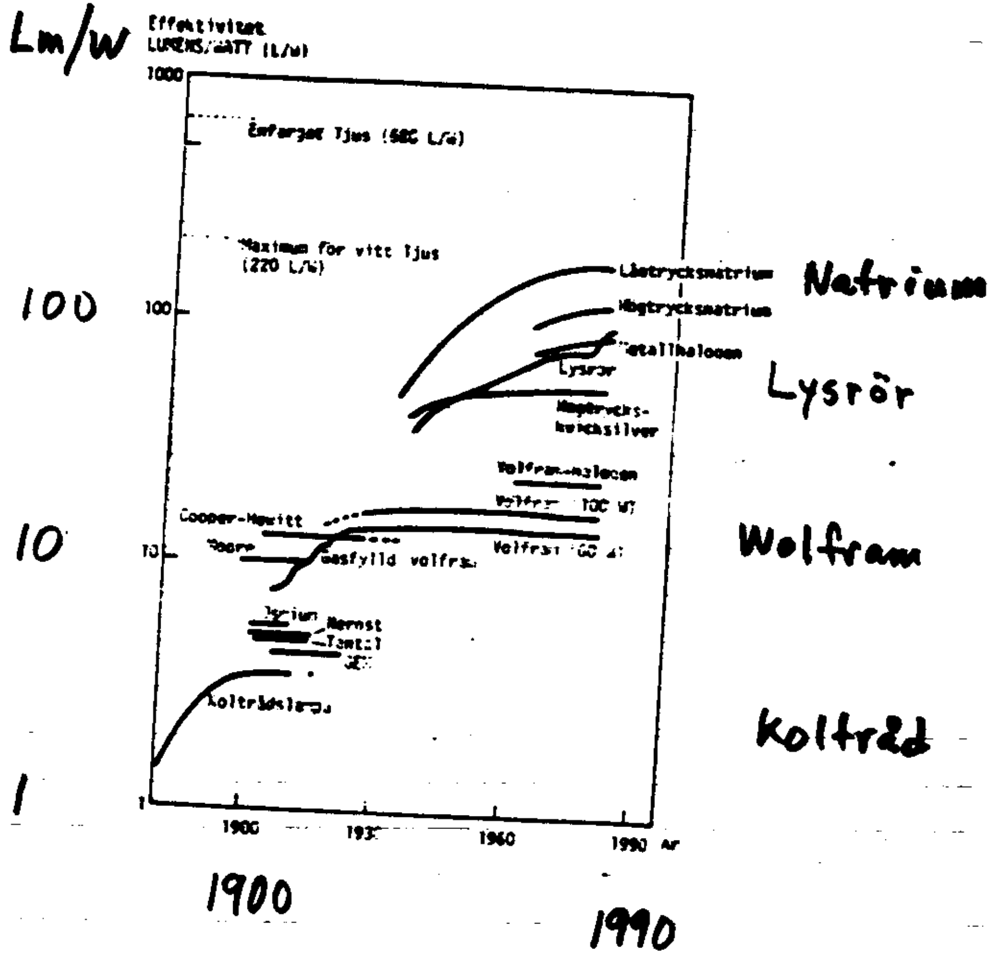
Space Heat - S F D

	KJ/m²/DD
Average stock, US	160
Sweden	135
New Construction, US (1980)	100
Sweden (1975 standard)	65
Mean Measured	
US - 97 Minnesota houses	51
Sweden - 39 Skane houses	36
Calculated, prefabricated homes	
US (a)	15
Sweden (b)	17

(a) Northern Energy Home, N.Y. City Area

(b) Faluhus, Stockholm Area

Figur 5.3. **Utveckling av lampors effektivitet**



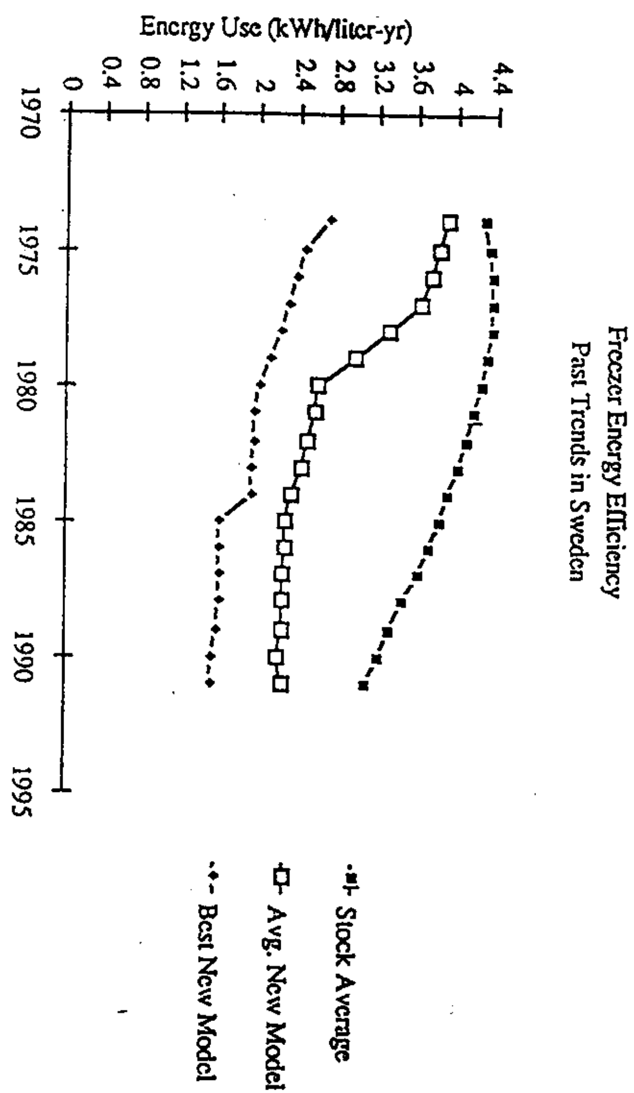


Figure 2. Historical progress of energy efficiency of freezers in Sweden. Source: see note 7.

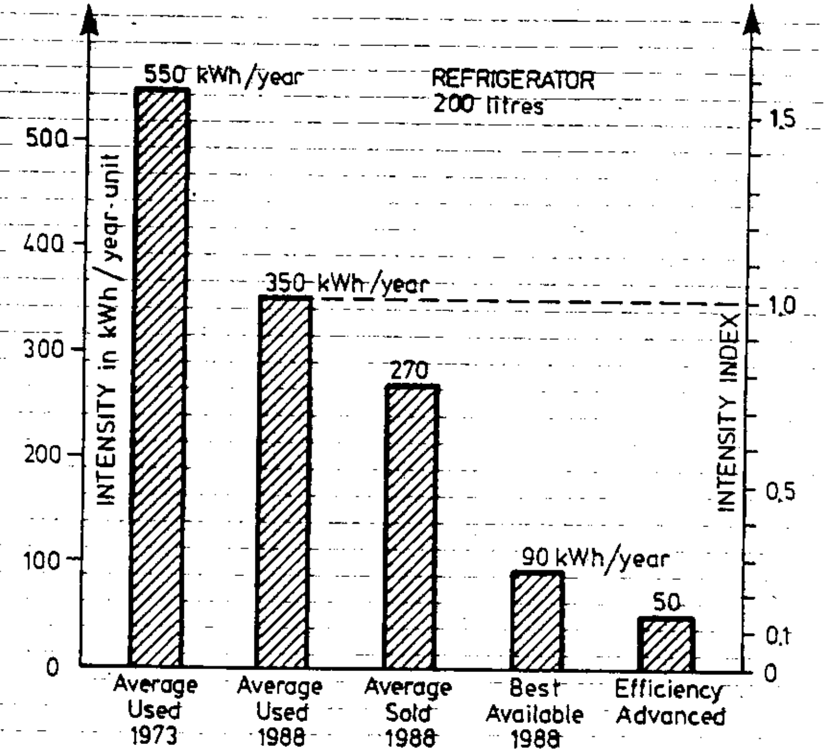
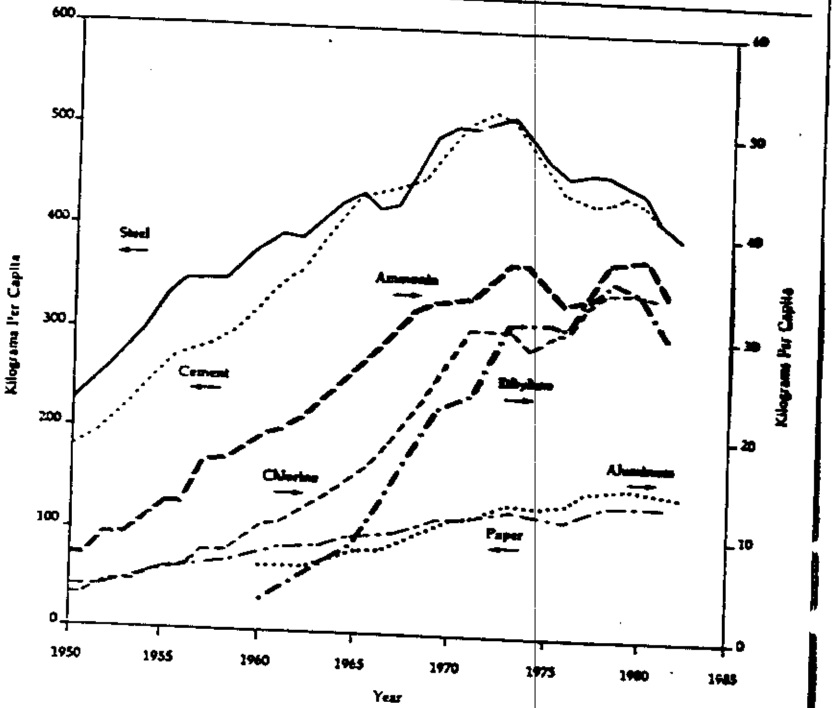
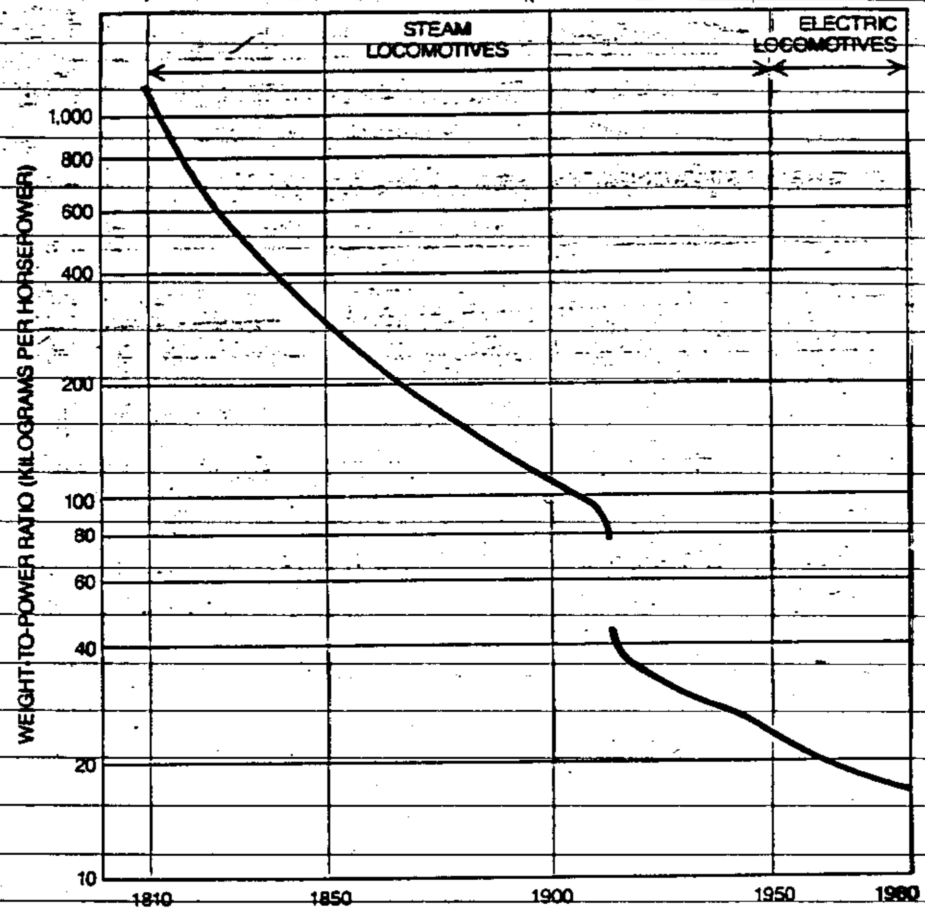


Figure 17. Trends in the Apparent Consumption Per Capita for Selected Basic Materials in Western Europe

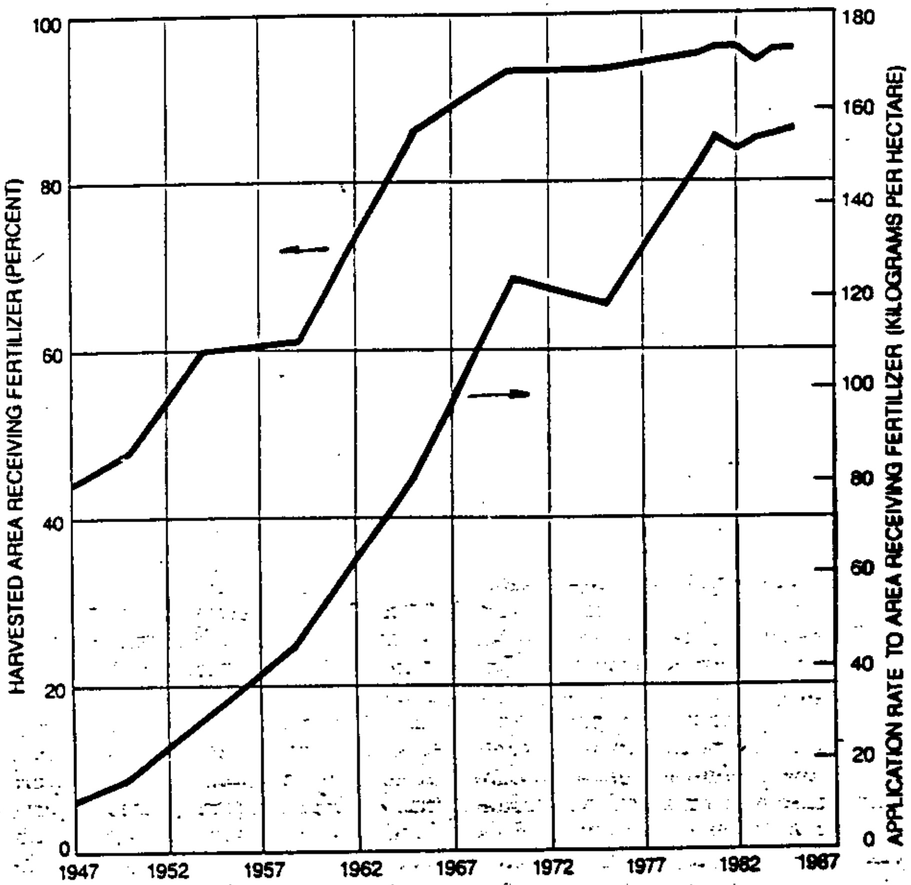


The data shown are aggregates of apparent consumption for the Federal Republic of Germany, France, and the United Kingdom. The ammonia data are for the Federal Republic of Germany and France only. The plotted points are 3-year running averages.

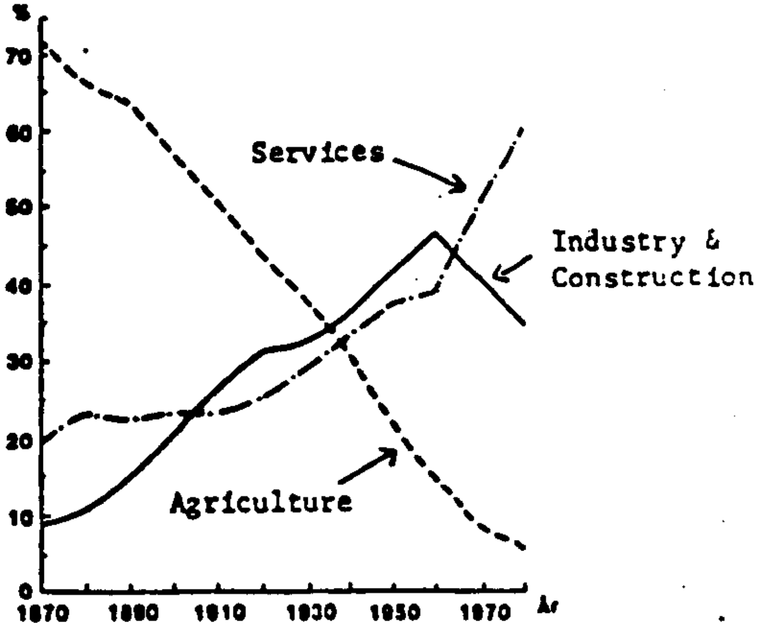
Source: M. Ross, E.D. Larson, and R.H. Williams, "Energy Demand and Materials Flow in the Economy," *Energy, the International Journal*, in press.



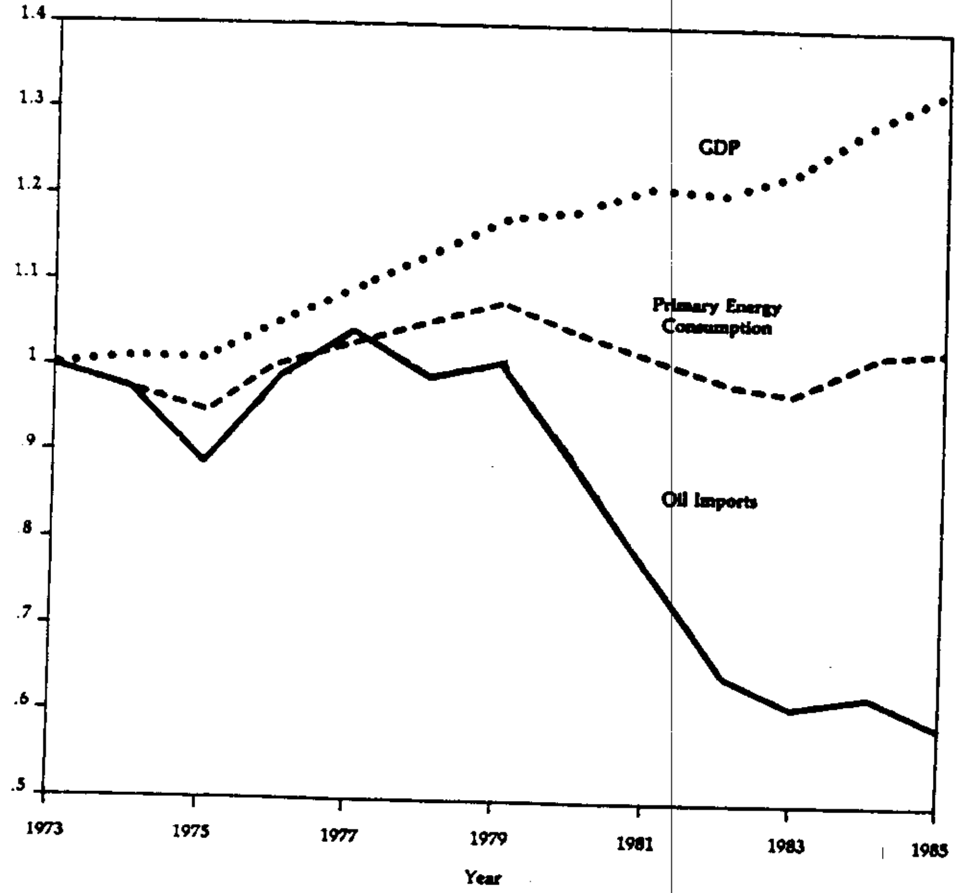
WEIGHT-TO-POWER RATIO of locomotives underwent a decrease of nearly 70-fold between 1810 and 1980; the decrease reflects many improvements in design and materials. In the mid-19th century iron boilers were replaced by boilers made of steel, a change that made possible lighter equipment and higher internal pressures. By 1900 the ratio had decreased by a factor of 10, and it continued falling during two world wars, reaching a level of about 25 kilograms per horsepower as electric locomotives were introduced around 1950. (The gap between 1910 and 1920 results from the disruption of data collection during World War I.) Similar (albeit less dramatic) improvements have been made in many industrial products. Substitution of materials and design changes that lead to more efficient use of materials are two of the factors responsible for the leveling off of demand for basic materials.



SATURATION OF MARKETS is among the factors that have contributed to a leveling off of demand for basic materials. The data in the illustration show why the market for nitrogenous fertilizer (which accounts for about 80 percent of all ammonia produced in the U.S.) is largely saturated. The black curve indicates the proportion of U.S. farmland on which corn is being grown that receives nitrogenous fertilizers. The colored curve indicates the amount of fertilizer applied to each hectare of such land. (A hectare is about two and a half acres.) Two factors suggest that demand for fertilizer will not grow much more in the years to come. Almost all corn land already receives fertilizer. Moreover, the benefits gained from applying more fertilizer diminish rapidly above the level reached in the past few years.



Sectoral Distribution of Employment in Sweden over Time ure 14. Primary Energy Consumption, Net Oil Imports, and Gross Domestic Product for Organisation for Economic Co-operation and Development Countries, Relative to the Values of These Quantities in 1973



ENERGY DEMAND – SOME GENERAL CONSIDERATIONS

SOCIETY → MANY ACTIVITIES

EACH ACTIVITY → ENERGY INTENSITY (I_I)
EACH ACTIVITY → CONTRIBUTION TO GDP (C_I)

$$\text{ENERGY DEMAND} = \sum_I C_I I_I$$
$$= \sum \alpha_I (GDP) I_I$$
$$= \left(\sum \alpha_I I_I\right) GDP$$

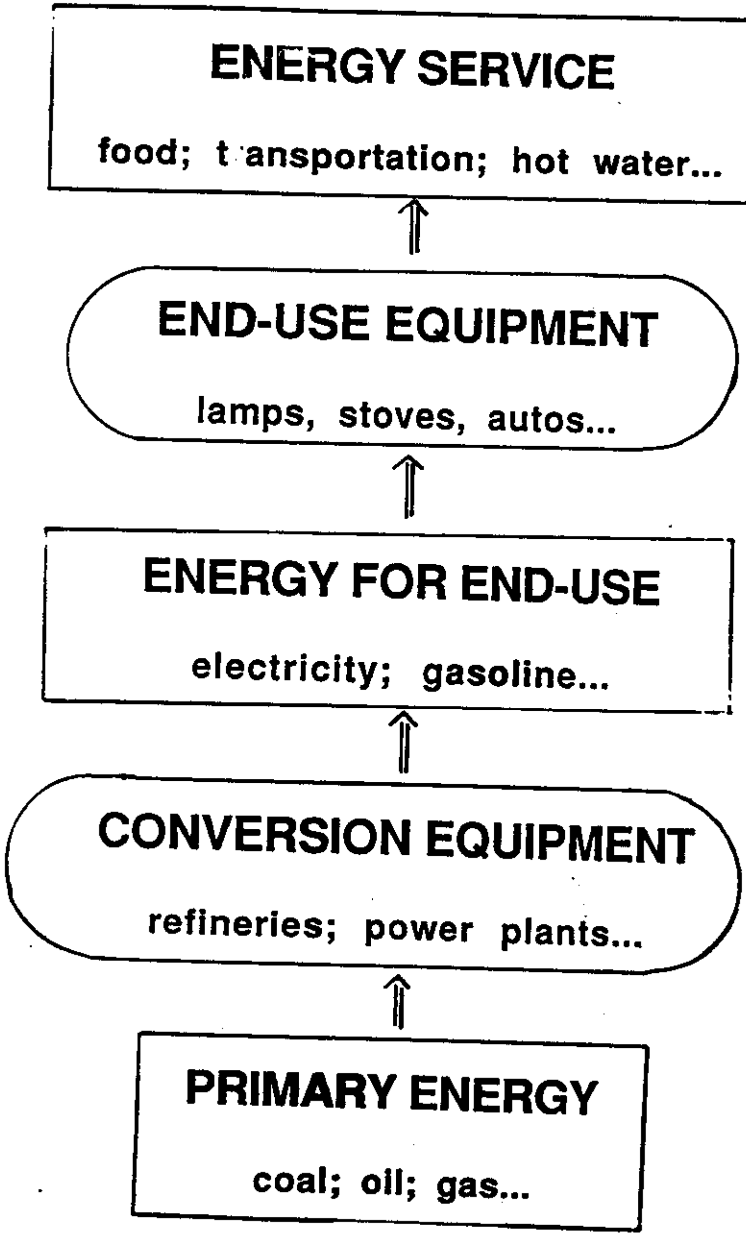
If $(\sum \alpha_i I_i)$ REMAINS CONSTANT, GDP ↑, ENERGY ↑
∴ ENERGY-GDP CORRELATION

BUT, CHANGES IN ENERGY DEMAND CAN ARISE FROM

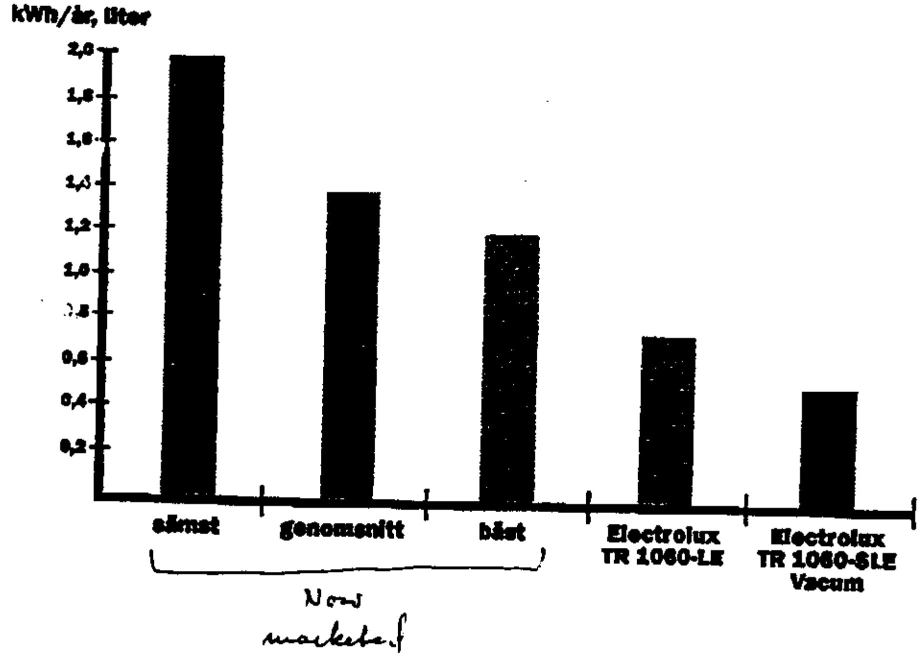
CHANGES IN ENERGY INTENSITY(I_I)
↓
TECHNICAL CHANGES
(I) EFFICIENCY IMPROVEMENTS
(II) PROCESS CHANGES
(III) PRODUCT CHANGES

CHANGES IN CONTRIBUTION TO GDP (C_I), I.E., CHANGES IN α_I
↓
STRUCTURAL CHANGES
(I) NEW COMPOSITION OF PRODUCTS SERVICES, I.E., NEW α_I's

RESULT → $(\alpha_I I_I)$ & $\sum (\alpha_I I_I)$ CAN DECREASE AND DECOUPLE ENERGY FROM GDP



Kyl -frys 1990 års modeller



Stock average ≥ 2.0 kwh/year/liter

USERS

lack of information/know-how
first cost sensitivity
energy costs small
"inherited" equipment (landlord/tenant)

MANUFACTURERS

little incentive

EQUIPMENT PROVIDERS

don't pay operating costs

ENERGY SUPPLIERS

preoccupation w. supply/centralizating monopolies

FINANCERS

GOVERNMENTS

AID INSTITUTIONS — large projects; no loop hopping

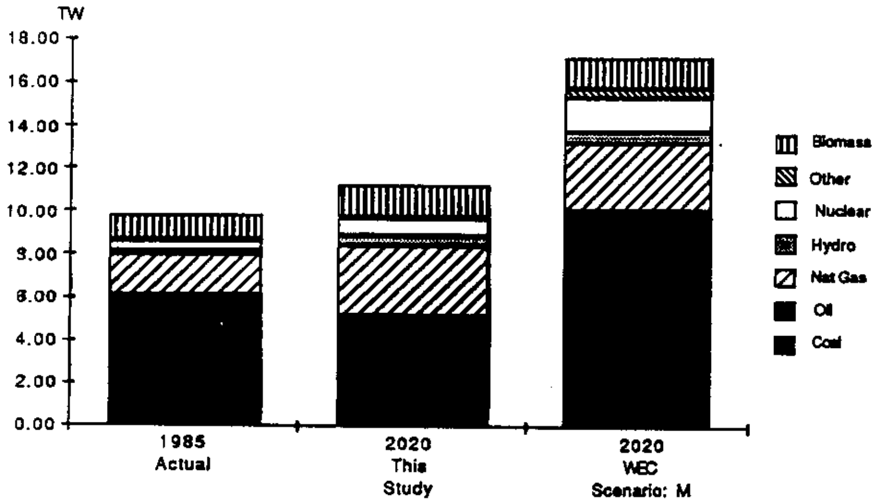
ENERGY AND WELL-BEING IN THE LONG TERM

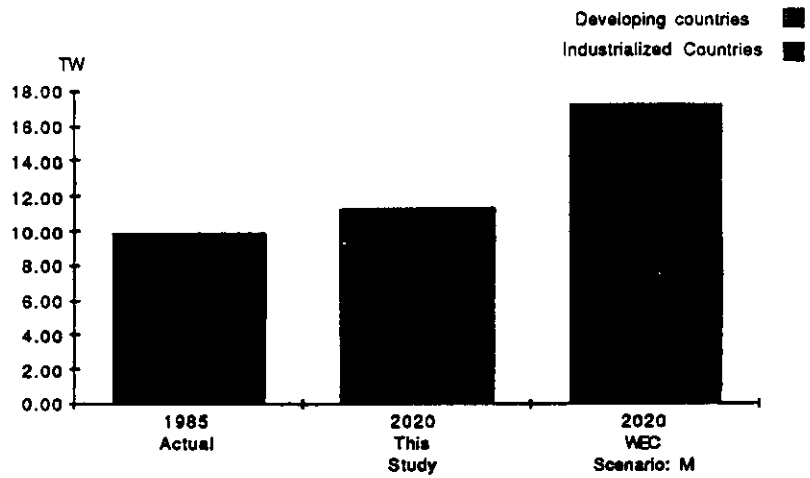
CONVENTIONAL WIDSOM:

- ENERGY/GNP COUPLING STRONG
- ENERGY USE UP 2X - 4X BY 2020, 2030

END USE ORIENTED GLOBAL ENERGY PROJECT:

- SHIFT UNDERWAY IN INDUSTRIALIZED COUNTRIES TO LESS-ENERGY-INTENSIVE ACTIVITIES
- OPPORTUNITIES IN BOTH INDUSTRIAL AND DEVELOPING COUNTRIES TO MAKE MORE EFFICIENT USE OF ENERGY
- CAN EVOLVE ENERGY FUTURE CONSISTENT WITH SOLUTIONS OF OTHER MAJOR GLOBAL PROBLEMS


TW
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
1985 Actual
2020 This Study
2020 WEC Scenario: M
Biomass
Other
Nuclear
Hydro
Nat Gas
Oil
Coal


Developing countries
Industrialized Countries
TW
18.00
16.00
14.00
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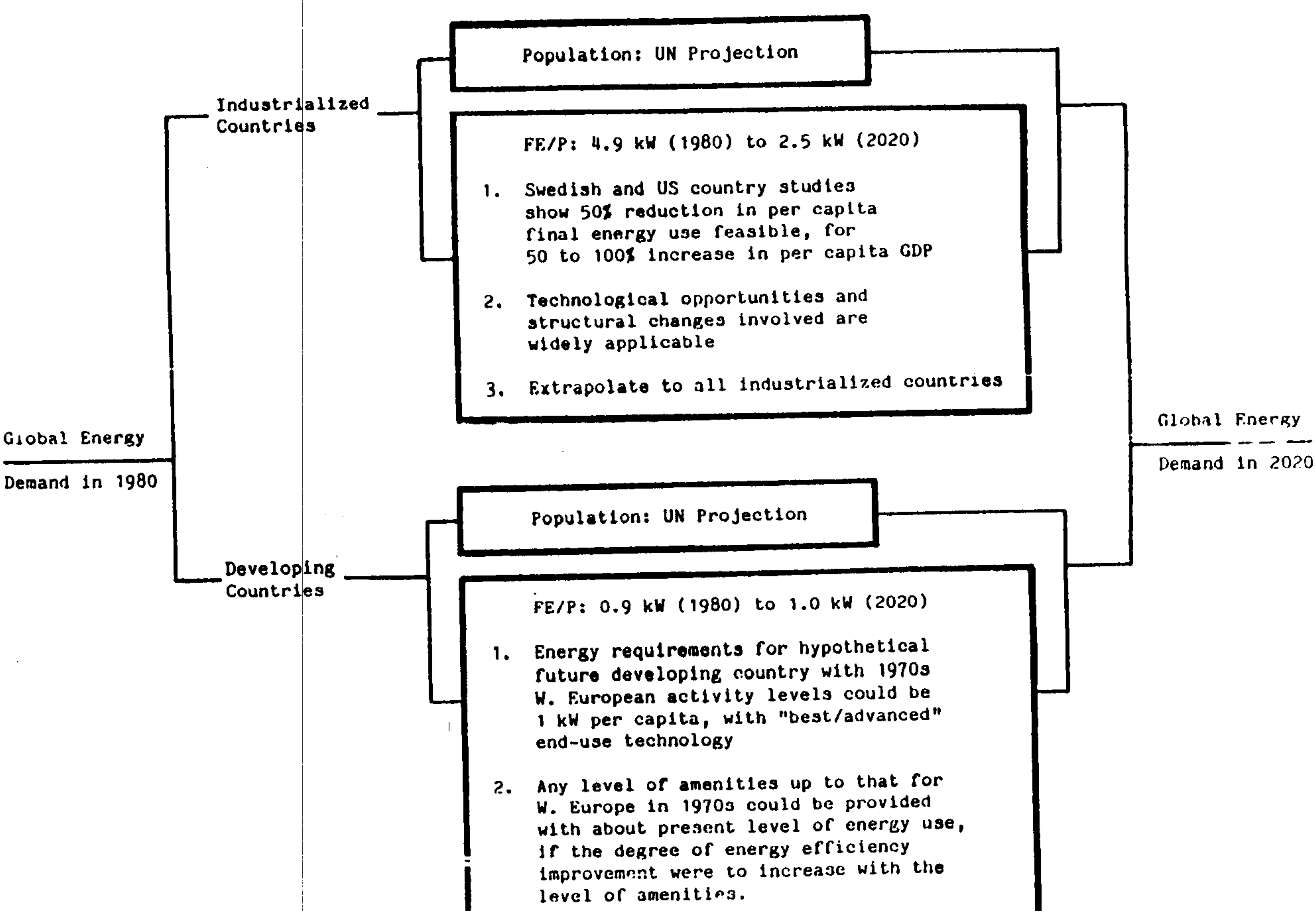
1985 Actual
2020 This Study
2020 WEC Scenario: M


Global Energy
Demand in 1980
Industrialized Countries
Population: UN Projection
FE/P: 4.9 kW (1980) to 2.5 kW (2020)
1. Swedish and US country studies show 50% reduction in per capita final energy use feasible, for 50 to 100% increase in per capita GDP
2. Technological opportunities and structural changes involved are widely applicable
3. Extrapolate to all industrialized countries
Developing Countries
Population: UN Projection
FE/P: 0.9 kW (1980) to 1.0 kW (2020)
1. Energy requirements for hypothetical future developing country with 1970s W. European activity levels could be 1 kW per capita, with "best/advanced" end-use technology
2. Any level of amenities up to that for W. Europe in 1970s could be provided with about present level of energy use, if the degree of energy efficiency improvement were to increase with the level of amenities.
Global Energy
Demand in 2020