# FINANCING GLOBAL ENERGY PERSPECTIVES TO 2050

Nebojša Nakićenović
*International Institute for Applied Systems Analysis*
*Laxenburg, Austria*

Hans-Holger Rogner
*International Institute for Applied Systems Analysis*
*Laxenburg, Austria*
and
*University of Victoria, Canada*

RR-96-9
June 1996

Reprinted from *OPEC Review*, Vol. XX, No. 1, March 1996.

**INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS**
**Laxenburg, Austria**

Reprinted with permission from *OPEC Review*, Vol. XX, No. 1, March 1996.


Printed by Novographic, Vienna, Austria.

# Foreword

Financing is likely to displace resource availability and environmental concerns as the dominant energy issue in the coming decades. Especially in developing countries, energy-sector financing will become more difficult as private-sector involvement increases and competition with other investments intensifies. In general, energy-sector investments yield lower returns than many investment alternatives, whereas public-sector financing capabilities are seriously hampered by already high levels of indebtedness.

This paper assesses these and other important issues concerning the financing of long-term global and regional energy perspectives. It applies the findings of the study jointly conducted by IIASA and the World Energy Council (WEC) presented in the report *Global Energy Perspectives to 2050 and Beyond*. The IIASA–WEC study formulates alternative scenarios with an integrated assessment framework of energy and environmental models. Three cases of economic and energy developments were formulated; the cases span six scenarios of energy supply alternatives extending until the end of the 21st century. The assessment of finance requirements for these six scenarios constitutes one of the key elements of the IIASA–WEC study.

Financing requirements of energy prospects underlying the scenarios are enormous. Cumulative capital needs between 1990 and 2020 range from US$13 to US$20 trillion (at 1990 prices). For comparison, the latter figure corresponds to the total world economic output in the year 1990. Supplying this amount may pose unprecedented financing problems, as the share of energy-sector investments in total world output is unlikely to increase from the current level of 3 to 4%. In addition, there will be a fundamental shift in investment activity from the energy sector to end-use infrastructures and end-use technologies, which are not accounted for in energy-sector investments but also require financing. These and other interesting findings of the joint IIASA–WEC study are summarized in this paper. The paper is only a beginning. Financing energy-sector development will continue to constitute an important part of IIASA research activities in the energy area.

*Peter E. de Jánosi*
Director

# Financing global energy perspectives to 2050

Nebojsa Nakicenovic
and Hans-Holger Rogner

AS INCOMES INCREASE around the world, people will demand more efficient, cleaner and less obtrusive energy services. This is the central message of the three cases, sub-divided into six scenarios, that are presented in the comprehensive report of the International Institute for Applied Systems Analysis and World Energy Council joint study, *Global Energy Perspectives to 2050 and Beyond.*[1] The scenarios cover a wide range of global energy developments — from a massive expansion of coal production to strict limits, from a phase-out of nuclear energy to a substantial increase, from carbon emissions in 2100, that are at only one-third of today's levels, to increases of more than a factor of three. Yet, for all the variations they explore among alternative energy systems, all manage to match the likely, continuing push by consumers for more flexible, more convenient and cleaner forms of energy. This paper summarises the financing requirements of the energy sector, in order to achieve these goals, with a particular emphasis on investment in the developing regions.

Capital requirements are assessed according to the traditional definitions of energy investment. They include capital for energy production capacities, for conversion and transformation facilities, for transmission and distribution infrastructures, and for complying with environmental standards. Capital requirements for energy end-use devices are not included in this assessment (traditionally they are

*Nebojsa Nakicenovic is from the International Institute for Applied Systems Analysis, Laxenburg, Austria; he is Leader of the Environmentally Compatible Energy Strategies Project at IIASA and Director of the Long-Term Energy Perspectives Study of the World Energy Council. Hans-Holger Rogner is from IIASA and the University of Victoria, Canada; he is Director of the Systems Analysis Institute for Integrated Energy Systems and Adjunct Professor at the Department of Mechanical Engineering at the University of Victoria.*

excluded from energy-sector capital requirements and are counted as durable consumer goods and business investment). The cumulative capital requirements from 1990 to 2020, across the cases, ranges from (US 1990) $13 trillion to 20 tr. This is to be compared with the gross world economic product (GWP) of $21 tr in 1990. Although both this range and magnitude of capital requirements are enormous, they are less intimidating when viewed in the context of economic growth, investment, savings, GWP and the size of capital markets implied by the scenarios. Capital requirements grow substantially, but more slowly, than GWP. This is true in all scenarios, but it does not imply that these capital requirements can actually be raised on domestic and international capital markets for energy investment.

The three cases, sub-divided into six scenarios, build on the analysis of the WEC Commission Report, *Energy for Tomorrow's World*.[2] The development paths of the six scenarios vary through 2020, but, after 2020, they start to diverge. Part of that divergence will depend on policy choices and development strategies. For example, two scenarios, that assume aggressive international cooperation focused on environmental protection and international equity, lead to less fossil fuel use than the other scenarios. Most of the post-2020 divergence will depend on technological developments and economic restructuring. Which energy sources in 2020 will be better matched to the more flexible, more convenient and cleaner forms of energy desired by the consumer? Which will have made the investment in research and development that will give them a technological edge? Which will have shifted their businesses away from providing just tons of coal or kilowatt-hours of electricity towards also providing more flexible, convenient and clean energy services to consumers?

The answers to these questions will be determined between now and 2020. Because of the long lifetimes of power plants, refineries and other forms of energy investment, there is insufficient turnover of such facilities to reveal large divergences across our scenarios prior to 2020, but the seeds of the post-2020 world will have been sown by then. The choice of the world's post-2020 energy systems is wide open now. It will be much narrower by 2020. Today's energy investment, especially in the developing world, will shape future opportunities and financing possibilities.

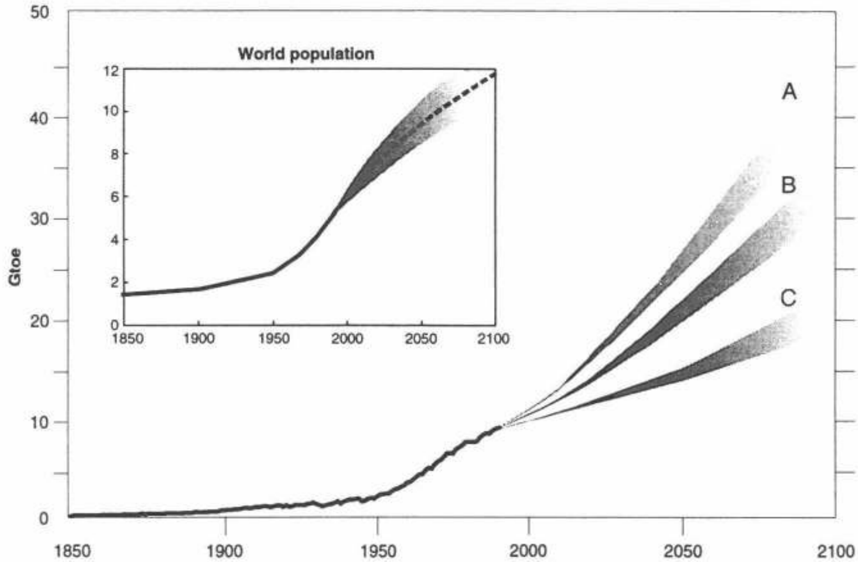
## 1. Main characteristics of scenarios

As in *Energy for Tomorrow's World*, the joint IIASA/WEC study report, *Global Energy Perspectives to 2050 and Beyond*, presents three sets of scenarios — Cases A, B, and C. It examines the possibilities beyond 2020 more thoroughly than could be done in *Energy for Tomorrow's World*. The principal focus is on the period between 2020 and 2050, but some preliminary results are also presented up to 2100. In brief, Case A presents a future of impressive technological improvements and high economic growth. Case B describes a future with less ambitious, though perhaps more realistic, technological improvements and, consequently, more intermediate economic growth. Case C presents a "rich ecologically driven"

**Table 1**
**A summary for three cases in 2050 and 2100**

| | Case A High Growth | Case B Middle Course | Case C Ecologically Driven |
|---|---|---|---|
| **Population** *(bn)* | | | |
| 2050 | 10.1 | 10.1 | 10.1 |
| 2100 | 11.7 | 11.7 | 11.7 |
| **GWP** *($(1990) tr)* | | | |
| 2050 | 100 | 75 | 75 |
| 2100 | 300 | 200 | 220 |
| **Energy intensity improvement** | medium | low | high |
| **PE/GDP** *(%/yr)* | | | |
| World (1999–2050) | –1.0 | –0.7 | –1.4 |
| World (1990–2100) | –1.0 | –0.8 | –1.5 |
| **Primary energy demand** *(Gtoe)* | | | |
| 2050 | 25 | 20 | 14 |
| 2100 | 45 | 35 | 21 |
| **Resource availability** | | | |
| Fossil | high | medium | low |
| Non-fossil | high | medium | high |
| **Technology costs** | | | |
| Fossil | low | medium | high |
| Non-fossil | low | medium | low |
| **Technology dynamics** | | | |
| Fossil | high | medium | medium |
| Non-fossil | high | medium | high |
| **$CO_2$ emissions constraint** | no | no | yes |
| **Carbon emissions** *(GtC)* | | | |
| 2050 | 9–15 | 10 | 5 |
| 2100 | 7–22 | 14 | 2 |
| **Environmental taxes** | no | no | yes |

**Figure 1**
**Global primary energy use, 1850 to present, and in the three cases to 2100**




*The insert shows global population growth, 1850 to present, and its projection[3] to 2100, in billions of people.*

future. It includes both substantial technological progress and unprecedented international cooperation, centred explicitly on environmental protection.

The key characteristics of the three cases are summarised in **table 1** and short descriptions are given in the Appendix. The following paragraphs provide more detail on what they have in common and where they differ.

## 1.1 Commonalities among scenarios

All three cases provide for significant social and economic development, particularly in the developing countries, and are therefore based on a substantial increase in financing requirements. They lead to improved energy efficiencies and environmental compatibility and, thus, for associated growth in both the quantity and quality of energy services.

World population is expected to double to 10 bn by the year 2050 and to increase to nearly 12 bn by the year 2100 (**figure 1**), while economic development continues throughout the world. According to the scenarios in this study, the result is a three-to-five-fold increase in world economic output by the year 2050 and a ten-to-15-fold increase by the year 2100. By the year 2100, per capita income in most of the currently developing countries reaches, and surpasses, levels characteristic of the developed countries today, making current distinctions between the two

**Table 2**
**Characteristics of three cases, sub-divided into six scenarios for the world in 2050**

| | Case A | | | Case B | Case C | |
|---|---|---|---|---|---|---|
| | A1 | A2 | A3 | B | C1 | C2 |
| Final energy *(Gtoe)* | 17 | 17 | 17 | 14 | 10 | 10 |
| Final energy mix *(%)* | | | | | | |
| Solids | 16 | 19 | 18 | 23 | 19 | 20 |
| Liquids | 42 | 36 | 33 | 33 | 34 | 34 |
| Electricity | 17 | 18 | 18 | 16 | 18 | 17 |
| Other[a] | 25 | 27 | 31 | 28 | 29 | 29 |
| Primary energy *(Gtoe)* | 25 | 25 | 25 | 20 | 14 | 14 |
| Primary energy mix *(%)* | | | | | | |
| Coal | 24 | 32 | 9 | 21 | 11 | 10 |
| Oil | 30 | 19 | 18 | 20 | 19 | 18 |
| Gas | 24 | 22 | 32 | 23 | 27 | 24 |
| Nuclear | 6 | 4 | 11 | 14 | 4 | 12 |
| Renewables | 16 | 23 | 30 | 22 | 39 | 36 |
| Resource use 1990–2050 *(Gtoe)* | | | | | | |
| Coal | 235 | 324 | 180 | 226 | 143 | 141 |
| Oil | 323 | 302 | 284 | 257 | 210 | 210 |
| Gas | 241 | 247 | 285 | 227 | 210 | 197 |
| Energy sector investment *($ tr)* | 1.2 | 1.7 | 1.2 | 1.1 | 0.7 | 0.7 |
| $/toe supplied | 50 | 67 | 47 | 56 | 50 | 50 |
| as % of GWP | 1.2 | 1.7 | 1.2 | 1.5 | 0.9 | 0.9 |
| Emissions | | | | | | |
| Sulphur[b,c] *MtS* | 23 | 86 | 15 | 35 | 4 | 3 |
| Nitrogen[c] *MtN* | 21 | 55 | 21 | 22 | 14 | 12 |
| Carbon, *GtC* | 12 | 15 | 9 | 10 | 5 | 5 |

a. *District heat, gas and hydrogen.*
b. *Unabated sulphur emissions in Case A could be three (A1) to five (A2) times higher, leading to unacceptable local and regional environmental impacts.*
c. *Preliminary global estimates.*

obsolete. Primary energy consumption grows less than global demand for energy services, due to improvements in energy intensities. Figure 1 shows a one-and-a-half-to-three-fold increase in primary energy requirements, across the three cases, by the year 2050, and a two-to-five-fold increase by the year 2100.

## 1.2 Distinctions among scenarios

Where all six scenarios diverge is in the dynamics of energy system transformation, as reflected in the contributions of individual primary energy sources — in other words, what percentage is supplied by coal, what percentage by oil, and so on. That divergence is shown in **table 2**, which summarises key numerical characteristics for all six scenarios. It presents a snapshot of how the scenarios would look in 2050.

**Figure 2**
**Evolution of primary energy shares, 1850–2100, for Case B**
%

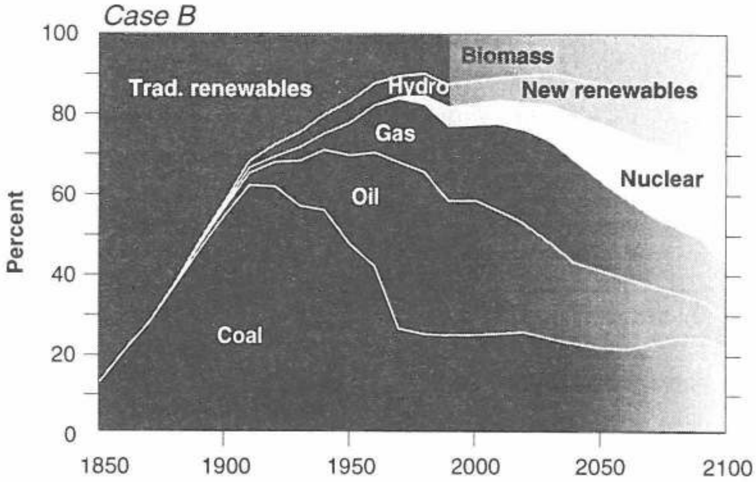



**Figure 2** presents the development, over time, of the structure of primary energy shares in Case B. Other cases, and their underlying scenarios, portray different dynamics of future changes in energy sources and in the structure of the energy system. However, the overall characteristic is a continuous shift from fossil to other sources of energy and towards higher quality and more flexible, cleaner forms of energy delivered to the final consumer.

Assumptions on the salient forces driving and shaping future energy systems are varied across the scenarios, in order to explore both differences and commonalities of alternative future primary and final energy structures. The scenarios vary: with respect to future technologies, in terms of penetration rates, performance and cost; with respect to the availability of energy sources, a question also closely related to technology; and with respect to geopolitical and policy issues, such as trade, technology transfer, environmental regulation and energy deregulation.

The high-growth Case A consists of three scenarios (Al, A2, A3); Case B, a single scenario; and the ecologically-driven Case C, two scenarios (C1 and C2). This reflects the possibility of alternative development strategies, with comparable levels of affluence and energy use. The three-pronged unfolding of Case A indicates that high levels of energy demand could be supplied by three fundamentally different strategies, which diverge from each other over time. In Case C, the differences between the two alternatives considered are less dramatic. For the intermediate Case B, a single scenario was developed. In general, this scenario is associated with more modest, perhaps also more realistic, changes; therefore, it did not seem useful to consider more extreme alternatives for the development of the energy system. Energy sector investment requirements are given with the greatest degree of detail for Case B, because it is less extreme than the other alternatives and because it illustrates the "middle course" of future financing requirements.

## 1.3 Implications for financing requirements

Having presented the cases, and how they unfold into six energy system scenarios, we now turn to their implications for investment and financing. All three cases reflect substantial growth for all energy industries to at least the year 2020, and profound changes beyond, leading to an enormous range and magnitude of capital requirements. The coming decades will bring numerous changes within and between energy sectors. Many new business opportunities will arise, linked to cleaner and more convenient fuels, to liquid rather than solid fuels, to grid and other interconnected supplies, and to more locally appropriate — often small-scale — energy sources and conversion technologies. However, the cases indicate that prospects will diverge after the year 2020, with energy industries and consumer needs embarking on mutually exclusive development paths across the six scenarios. All these developments would have profound implications for future financing requirements. This is reflected in the range of cumulative capital requirements to the year 2020 — $13–20 tr across the six scenarios.

Despite its huge resource base, coal could be particularly vulnerable, due to increased competition from other energy sources and environmental constraints in response to sulphur dioxide, particulate, methane and carbon dioxide emissions. In contrast, the oil industry and, to an even greater extent, the natural gas industry have a long future ahead. The prospects for natural gas, however, will have to be enhanced by aggressive exploration and resource development. New markets will need to be developed for the traditional fuels, with the recognition that the shift from just selling primary or final energy to marketing energy services will continue and intensify.

In all scenarios, renewable energy sources undergo significant expansion. Despite a slower start than depicted in other studies, the outlook given here is clearly bullish in the long run, a view also taken in the WEC's *New Renewable Energy Resources: a Guide to the Future*.[4] The development and diffusion of new renewables are seen as requiring several OECD countries to take leading roles, with subsequent large technology transfers to developing countries. In the long run, the biggest market for renewables will be in the South.

For nuclear power, prospects beyond the year 2020 are more uncertain. The potential for nuclear energy to make a substantial contribution will depend on whether public concern about operational safety, waste disposal and proliferation can be alleviated. If such concern persists, nuclear power could wither away; however, it may be successfully challenged to introduce a new generation of facilities that are more acceptable.

Technological progress and appropriate investment, to match energy sources to the desire for the more flexible, convenient and clean forms of energy required to service consumer needs, are crucial, but several decades of turnover of capital stock will be required to achieve that match. In the meantime, unless the long-term goal is itself matched by the appropriate policies and investment decisions, it will become even harder and more costly to change courts. Investment decisions to the year 2020 are, therefore, an important concern — not simply because of the tremendous sums of money involved. Work also needs to be done to extend the analysis beyond final energy, to cover energy services and find out what new institutional mechanisms are required to facilitate energy-financing and the implementation of environmental policies attracting ever-widening support.

We believe this study has identified patterns that are robust across a purposely broad range of scenarios. They can never turn an uncertain future into a sure one, but they can delimit future energy-financing requirements consistent with the range of scenarios.

## 2. Investment and financing

### 2.1 Energy capital markets and investment

Although the capital requirements for all three cases are enormous, they are less intimidating when looked at in the context of economic growth, investment, savings and the size of capital markets implied by the scenarios. The current average global investment rate is about 22 per cent of GWP — 21 per cent in the industrialised countries and 24 per cent in the developing countries. In the reforming economies, recent gross domestic product (GDP) declines have been matched by reduced savings, keeping the investment rate relatively constant at about 20 per cent.[5] Although the level of energy investment, as a share of economic product and total investment, varies greatly among countries and between different stages of economic development, on average, between three and four per cent of GDP is invested in the energy sector, and this ratio is expected to remain relatively stable.[6] Average ratios of energy to total investment are also quite stable, at about 20 per cent — approximately ten per cent for power sector investment and 5–10 per cent for upstream operations in the coal, oil and gas sectors. Deviations from these averages could be as high as a factor of two to three over the next decades. Large energy exporters or rapidly developing countries, for example, experience higher rates.

Capital markets have been growing faster than total GDP for some time. Present annual global energy investment amounts to at least ten per cent of international credit financing, which is about $3.6 tr.[7] With capital markets growing relative to GDP, and assuming relatively stable future energy investment ratios, capital market size appears not to be a limiting factor for energy sector finance.

The real challenges in raising funds for energy investment are the perceived risks to investors and adequate rates of return. Returns in the energy sector do not always compare well with many private investment alternatives, not even with other infrastructure investment. Between 1974 and 1992, for example, electricity projects, supported by the World Bank, realised average rates of return of 11 per cent per year, while urban development and transport returns were 23 and 21 per cent, respectively.[8] Also important is the allocation of funds within the energy sector. Rate of return considerations discriminate against smaller-scale, clean and innovative energy supplies, and against investment in energy efficiency improvements. Market size and product mobility often favour investment in oil exploration over, for example, natural gas or energy conservation.

Until now, in many countries, much of the energy sector has been publicly owned, and, in most developing countries, substantial international funding has supplemented limited domestic capabilities. The share of private sector capital has usually been less than 20 per cent. More recently, growing public and private debt, in industrialised and developing countries alike, has made energy sector financing, with its long amortisation periods, more difficult. Privatisation has become the accepted political remedy. A second development, increasing the likely dependence of energy investment on private capital, is stagnation in international development finance, despite an increase in international credit financing from five per cent of gross world product, or about $175 bn, in 1973, to 17 per cent, or about $3.6 tr, in 1993.[7] Although energy financing, therefore, must come increasingly from the private sector, government policies can make a difference: by restructuring subsidies that reduce non-commercial investment risks consistent with long-term development targets; by encouraging energy prices that reflect real costs; and by maintaining a stable political climate that reduces investment risks and broadens access to international capital markets. Nonetheless, the bottom line for energy investment remains unchanged — returns must, at least, match opportunity costs.

**Table 3** quantifies the cumulative energy sector capital requirements for Cases A, B and C, according to traditional definitions of energy investment. They include capital for energy production capacities, for conversion and transformation facilities, for transmission and distribution infrastructures, and for complying with environmental standards. They do not include investment in end-use technologies, such as furnaces, appliances and vehicles, because they are traditionally counted as durable consumer goods or business investment. However, the fact that the performance of end-use technologies plays such an important role in all three cases in this study is a strong argument in favour of new approaches to evaluating energy sector investment. Integrated resource planning, for example, has begun to extend the traditional energy sector perspective to include investment in end-use technologies. Approaches that assess both supply options and end-use options, and both expansion and conservation, will be increasingly essential in all the futures represented by the three cases.

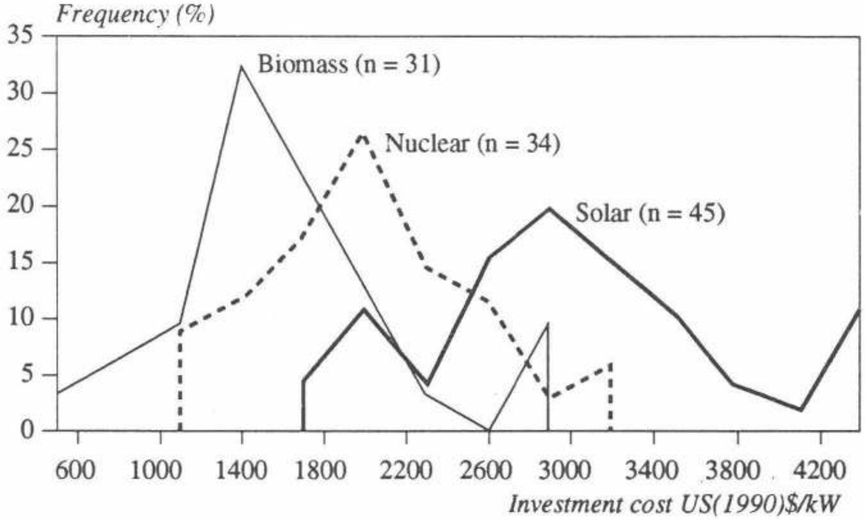
A simple "back of the envelope" calculation can be used to illustrate the need to widen the definition of energy investment to the whole energy system, including end-use. Case C relies heavily on measures to improve end-use efficiency. For the period 2020–50, table 3 shows cumulative investment in Case C to be only slightly more than half the investment in Case A. Compared with Case B, Case C

## Table 3
## Cumulative investment in energy sector by region, 1990–2020 and 2020–50

| | Case A[a] | | Case B | | Case C[b] | |
|---|---|---|---|---|---|---|
| | 1990–2020 | 2020–50 | 1990–2020 | 2020–50 | 1990–2020 | 2020–50 |
| Cumulative *($(1990) tr)* | | | | | | |
| OECD | 8 | 10 | 7 | 10 | 5 | 4 |
| REFs | 3 | 6 | 2 | 5 | 2 | 3 |
| DCs | 9 | 18 | 7 | 15 | 6 | 11 |
| World | 20 | 34 | 16 | 30 | 13 | 18 |
| As share of GDP *(%)* | | | | | | |
| OECD | 1.1 | 0.8 | 1.1 | 0.9 | 0.7 | 0.4 |
| REFs | 9.0 | 4.3 | 7.9 | 5.9 | 7.0 | 3.9 |
| DCs | 3.7 | 2.3 | 3.6 | 2.8 | 2.9 | 1.8 |
| World | 1.9 | 1.6 | 1.8 | 1.7 | 1.5 | 1.1 |
| Per unit of primary energy *($(1990)/toe)* | | | | | | |
| OECD | 50 | 49 | 51 | 60 | 46 | 42 |
| REFs | 56 | 53 | 67 | 74 | 54 | 63 |
| DCs | 44 | 49 | 40 | 51 | 42 | 48 |
| World | 48 | 49 | 48 | 56 | 45 | 49 |

*a. A1 scenario.*
*b. C1 scenario.*
*OECD = Organisation of Economic Cooperation and Development.*
*REFs = countries with reforming economies.*
*DCs = developing countries.*

## Figure 3
## Range of investment cost distributions as a histogram used to assess current and future financing requirements




*n = number denoting sample size.*

has the same GWP, but the traditional energy investment is $400 bn less, or only 64 per cent of the investment in Case B. This looks almost like a "free lunch." This picture may change drastically, if investment in end-use technologies is included. Case C uses four Gtoe less final energy, or six Gtoe less primary energy, than Case B (see table 2). Assume that this reduction is achieved with additional investment for more efficient end-use equipment and devices at levelised investment costs, comparable with average energy sector investment needs. For example, an average investment of $50/toe (see tables 2 and 3) would lead to total additional end-use capital requirements of $300 bn by the year 2020, for a reduction in primary energy needs of six Gtoe. This simple calculation suggests that the total investment in the energy system for Case C could be of the same magnitude as for Case B. However, should end-use investment turn out to be higher or lower than assumed in this overly simplistic calculation, the relative attributions could change radically.

## 2.2 Investment requirements and technological change

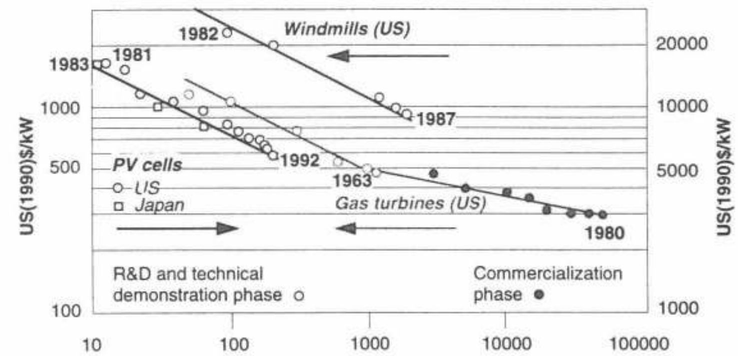
Future specific investment costs, especially for new energy technologies, can depend on the cumulative learning effects. The three cases incorporate future technological improvements in performance and capital cost reductions with increasing diffusion, especially of new technologies, such as photovoltaics, hydrogen production or fuel cells. Capital costs of many conventional technologies also decline, albeit at a much slower rate, due to the inherently incremental improvement of mature technologies.

The full report of the joint IIASA/WEC study devotes considerable space to the dynamics of technological progress and technological innovation and diffusion, drawing on the inventory of 1,400 technologies.[9,10] We pooled all available estimates of investment requirements from the inventory, so that the respective medians and ranges could be extracted from the data. For example, investment costs for solar systems and nuclear reactors were derived from 45 and 34 independent estimates, respectively, as shown in **figure 3**. Near-term investment requirements assumed for the three cases were derived from the medians of the empirical cost distributions. Lower ranges defined the scope for future cost reductions, along the learning curves that are realised at different rates in the three cases.

The "learning" or "experience" curve characterises the pattern of diminishing costs with increasing cumulative production. Its specific shape depends on the individual technology in question, but it is a persistent characteristic of all successful, standardised technologies. Usually there are steep cost improvements during the research and development phase. For example, **figure 4** shows an 18 per cent reduction in investment costs, per doubling of cumulative production of combustion turbines. These are followed by more modest improvements, after commercialisation — for combustion turbines, seven per cent per production doubling. Improvements continue for some time at a slower pace and then cease, as the technology approaches the end of its life-cycle.[13]

Cases A, B and C incorporate technological change through learning curve effects for various individual and generic technologies. These reflect different

**Figure 4**
**Technology learning curves; improvement in the costs per unit of capacity versus cumulative installed capacity**




*Sources: adapted from MacGregor et al*[11] *and Christiansson.*[12]

priorities and varying impacts of related features, such as international trade in some technologies and the scope for local development and manufacture of others.

In Case A, there is substantial advancement of all new, and currently marginal, energy production and conversion technologies. These advances are demonstrated across the board: for hydrocarbon exploration and extraction; for nuclear electricity generation and hydrogen; and for renewable sources of electricity generation and biofuel production and conversion. In Case B, the advances are less substantial than in Case A, reflecting less concentrated research, development and diffusion efforts. In this respect, Case B lags behind Case A by 30 per cent. The bulk of the effort, in Case B, is put into the incremental improvement of existing technologies consistent with the case's less concerted research and development efforts. For Case C, learning curve effects by design favour low-carbon fossil and renewable technologies. These technologies benefit from improvements equal to those in Case A. All other technologies develop as in Case B.

Technological change leads to capital cost reductions in all cases, with an increasing scale of new technology deployment. This means that the future capital costs in the joint IIASA/WEC study might be smaller, due to technological change, compared with other studies that assume more static technological development.

There are other reasons for a possible over-estimate of actual capital requirements. All cases explicitly adopt a cost-optimal structure of the energy system. Reality might be different, especially if the chronic lack of capital continues to trouble the developing world. Replacement of old vintages might be postponed, leading to lower capital requirements. However, if departures from the outlined investment trajectories are too great, they may lead to energy supply shortages and, thus, to a loss of economic output, which would then be lower than assumed in the three cases.

On the other hand, the possibility of under-estimation cannot be ruled out either. For example, it is difficult to accurately account for the long-term ratio of peak-to-base load capacity, and the peak capacity may be higher than anticipated in the three cases. Also, if natural gas supplies cannot be brought to the market place at the rate indicated, the relatively low capital-intensive natural gas-fired electricity generation needs to be replaced by more capital-intensive coal or hydropower plants, and cumulative investment may turn out to be higher than calculated in the joint IIASA/WEC study. On the whole, capital requirements, implied by the three cases, can be considered to represent a realistic and a detailed account of the financing needs of these three alternative futures.

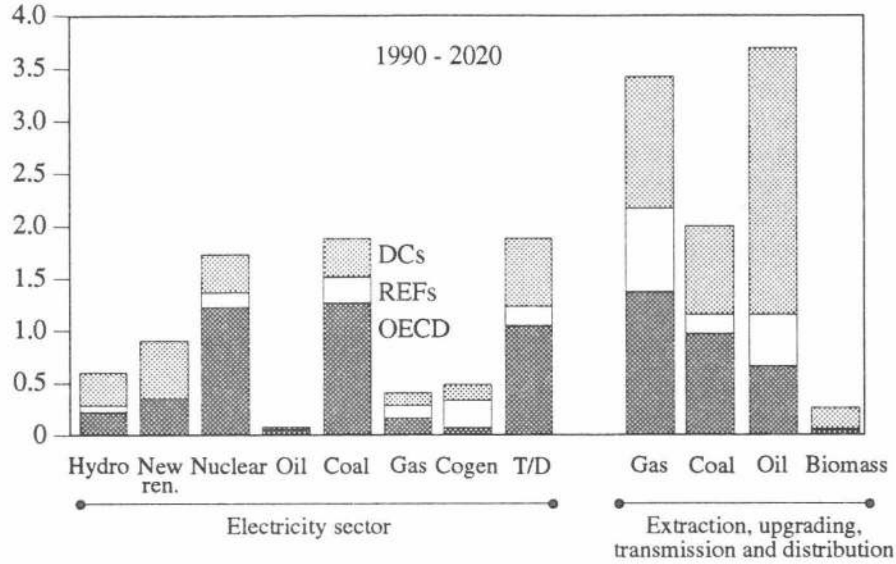
## 2.3 Energy investment in the three cases

Looking first at cumulative capital requirements from 1990 to 2020, table 3 shows the range across the cases to be from $13 to 20 tr. The developing region's share rises sharply, from today's 25–30 per cent to between 42 and 48 per cent, and it becomes the largest energy capital investment market in all cases. Looking at energy investment, as a share of regional GDP, the reforming countries rank the highest, diverting 7–9 per cent of regional GDP to the energy sector. They will be burdened by slow initial economic growth. At the same time, they will need to replace obsolete energy infrastructures, and it is likely to be extremely difficult to attract the required capital to the energy sector. Developing countries invest 3–4 per cent of GDP in the energy sector, while OECD region investment is the lowest, at 0.8–1.1 per cent of GDP. By and large, it takes a greater effort to build up an energy infrastructure than to expand and maintain an existing one. Finally, the bottom section of table 3 shows an upward trend for specific investment (dollars per unit of primary energy) in all cases, even though future energy investment does not increase relative to GDP.

To illustrate what goes into the cumulative capital requirements of table 3, **figure 5** breaks down the different components for Case B. The figure shows that investment in electricity generation is dominated by the OECD, especially for the expansion of nuclear and coal-fired capacity. New renewable and hydropower investment is concentrated in developing regions. Given the current economic unattractiveness of most new renewables, this reflects substantial learning curve effects. Over $250 bn are invested in the development of a bio-fuel production infrastructure. The accepted view, that oil and gas generally are profitable investment opportunities, is reflected in both the volume and regional breakdown in the figure.

From 2020 to 2050, capital requirements in table 3 grow substantially in absolute terms, but still more slowly than GDP. This is true in all scenarios. It reflects, first, the shift from supply-side investment (included in table 3) to end-use technology and infrastructure investment (not included in table 3). Had we been able to include the latter, we estimate it might have increased the numbers by

**Figure 5**
**Breakdown of global cumulative energy sector investment for Case B, 1990–2020**
*trillion US(1990)$*




50–100 per cent. Secondly, the declining share of GDP going to energy investment reflects continued progress along technological learning curves, throughout the energy system. Had these been excluded, the capital requirements of the electricity sector in the OECD region would have been 8–15 per cent higher for 1990–2020. In developing regions, the impact would have been greater — an increase of 25–40 per cent, due to heavy investment in new renewables and hydropower. Finally, and most importantly, capital requirements grow slower than GDP, because of the continuation of energy intensity improvements, characteristic for all three cases.

## 2.4 Other estimates of financing requirements

The figures in table 3 are consistent with the estimates of *Energy for Tomorrow's World*. There, the estimated global capital requirement for 1990–2020 was $30 tr. This included efficiency improvement-related investment of approximately $7 tr, which is excluded here, but excluded learning curve effects in lowering future investment, which are included here. Once both corrections are made, the figures are consistent. *Energy for Tomorrow's World* was also used as the basis for a simplified analysis by Hyman.[8] Assuming an average capital cost of $750/kW of generating capacity, he calculated the total 1990–2020 investment requirement to be $4.3 tr for the electricity sector. For comparison, our detailed calculations estimate requirements to be 75–125 per cent higher.

Annual capital requirements for energy investment rise from a little less than $400 bn in 1990 to $500–750 bn by 2020 and $0.7–1.2 tr by 2050. A large share of this investment would probably have to be financed externally. Hyman estimates that a third of the global capital spending based on *Energy for Tomorrow's World* electricity needs would be externally financed. This implies that a large share of total energy investment would also need to come from international capital markets or development assistance. That compares with total funds transferred to developing countries in 1990 of about $140 bn, to a total debt service for these countries of about $150 bn, and to total official development assistance from the OECD countries of about $50 bn.[14]

As its title suggests, the WEC report on *Financing Energy Development: The Challenges and Requirements of Developing Countries*[15] investigated the challenges facing energy financing in the developing countries. The approach pursued by that study complements the approach of this joint IIASA/WEC study in many respects. While the joint IIASA/WEC study made extensive use of formalised models, to assure consistency between economic development, energy service demand, capacity build-up rates, resource development and extraction, grounded on detailed technology cost data, the WEC study on developing countries drew on the expertise of many individuals and institutions, including international development banks. The study focused more on the institutional and policy aspects, financing mechanisms, regulation, foreign investment, the role of international development agencies, etc, and less on detailed calculations of energy investment requirements. The joint IIASA/WEC study accounted for investment needs on a technology-by-technology basis, separately, for production, conversion, transmission and distribution. The specific investment costs are dynamic and account for learning curve and economies of scale effects. It should also be noted that the underlying energy development scenarios have not been harmonised between the two groups. Finally, the geographical and temporal scopes differ: the joint IIASA/WEC study includes the entire world, up to the year 2050, in greater detail, and to 2100, in outline, while the WEC study on developing countries considers the time period 1990–2020.

One should note another fundamental difference, when comparing the sets of investment requirements produced by the two groups. The WEC study on developing countries excludes investment for energy exports in their estimates. The investment volumes reported are based on meeting developing countries' energy demand only. It is also unclear whether the volumes include investment for the replacement of retired plant and equipment. In addition, no capacity cushions are factored into the estimates for upstream oil and gas investment.

The longer time-horizon of the joint IIASA/WEC study introduces a distinctly different investment profile than is found in the more static calculations of the WEC study on developing countries. Construction times for new power plants can be as long as a decade, or more. Therefore, the construction starts of capacity

**Table 4**
**Cumulative energy investment requirement in developing countries, reproduced from the WEC report,[15] 1990–2020**
*$(1990) trillion*

| Sector | Latin America | MENA[a] | Sub-Saharan Africa | DCs Pacific | South Asia | All DCs |
|---|---|---|---|---|---|---|
| Electric power | 1.10–1.80 | 0.30–0.50 | 0.20–0.40 | 0.53–1.12 | 0.30–0.60 | 2.43–4.42 |
| Oil[b] | 0.07–0.24 | 0.06–0.16 | 0.04–0.13 | 0.03–0.13 | 0.06–0.12 | 0.26–0.78 |
| Natural gas | 0.03–0.07 | 0.06–0.08 | 0.002–0.04 | 0.01–0.03 | 0.01–0.03 | 0.11–0.25 |
| Coal | 0.01–0.03 | 0[c] | 0.003–0.03 | 0.03–0.07 | 0.01–0.05 | 0.05–0.18 |
| Biomass and renewables | 0.06–0.40 | 0.01–0.06 | 0.03–0.17 | 0.08–0.41 | 0.05–0.19 | 0.23–1.23 |
| **Total** | **1.27–2.54** | **0.43–0.80** | **0.28–0.77** | **0.68–1.76** | **0.43–0.99** | **3.08–6.86** |

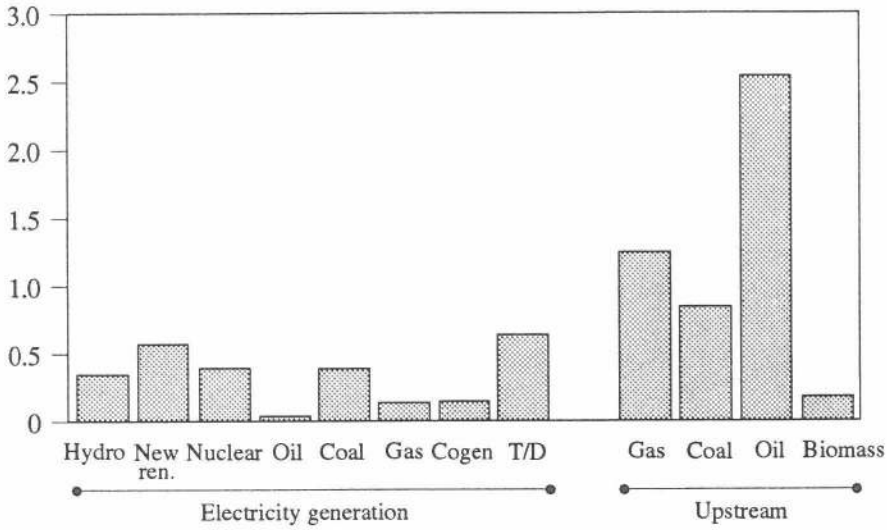
*a. MENA: Middle East and North Africa.*
*b. Includes refining.*
*c. No additional capacity required.*

**Table 5**
**Cumulative energy investment requirement in developing countries, based on Cases A[a], B and C[b], 1990–2020**
*$(1990) trillion*

| Sector | Latin America | MENA[c] | Sub-Saharan Africa | DCs Pacific[d] | South Asia | Centrally Planned Asia | All DCs |
|---|---|---|---|---|---|---|---|
| Electric power | 0.31–0.38 | 0.16–0.22 | 0.16–0.21 | 0.45–0.63 | 0.33–0.46 | 0.74–1.15 | 2.15–3.03 |
| Oil[e] | 0.49–0.71 | 0.85–1.42 | 0.24–0.43 | 0.11–0.24 | 0.02–0.04 | 0.26–0.38 | 1.97–3.22 |
| Natural gas | 0.27–0.32 | 0.50–0.60 | 0.03–0.04 | 0.13–0.16 | 0.16–0.25 | 0.12–0.17 | 1.25–1.49 |
| Coal | 0.03–0.04 | 0[f] | 0.11–0.33 | 0.04–0.04 | 0.10–0.12 | 0.44–0.79 | 0.72–1.32 |
| Biomass and renewables | 0.03–0.06 | 0.007–0.01 | 0.03–0.08 | 0.03–0.03 | 0.01–0.03 | 0.07–0.18 | 0.25–0.30 |
| **Total** | **1.20–1.46** | **1.61–2.13** | **0.63–1.03** | **0.77–1.10** | **0.72–0.81** | **1.65–2.67** | **6.59–9.20** |

*a. A1 scenario.*
*b. C1 scenario.*
*c. MENA: Middle East and North Africa.*
*d. Range for coal and biomass is too small at the level of significance.*
*e. Includes refining.*
*f. Investment is very low.*

**Figure 6**
**Cumulative energy sector capital requirement in developing countries for Case B, 1990–2020**
*trillion US(1990)$*




additions, scheduled to connect to the grid in the early 2020s, will take place during the 2010s. Consequently, the financing needs arise during that decade and are included in the 1990–2020 cumulative investment requirements.

**Table 4** summarises the energy investment requirements in the developing countries, for the period 1990–2020, reproduced from the WEC report. **Table 5** summarises investment requirements from the joint IIASA/WEC study. The agreement between the two studies is surprisingly high, given the fundamentally different study approaches and underlying methodologies. The first notable difference (see tables 4 and 5 and **figure 6**) concerns the total investment volume. The lower range of the joint IIASA/WEC study of $6.6 tr barely overlaps with the upper range of the other estimate of $6.9 tr. The lower range estimates differ by a factor of two versus a factor of one and a half for the upper ranges. The sectoral breakdown reveals that the upstream investment in oil, natural gas and coal exceeds that of the WEC study on developing countries by an order of magnitude. Electric power development investment, however, agrees reasonably well between the two studies. Here, the estimates of the WEC study on developing countries are somewhat higher, which can be attributed to the static specific investment costs used in the calculations. In addition, the share of hydropower in electricity generation is generally 50 per cent higher than in the joint IIASA/WEC study. The rapid hydropower capacity expansion implies the utilisation of fairly capital-intensive hydro resources. In contrast, the joint IIASA/WEC scenarios indicate an intensification of thermal power generation, based on natural gas. Natural gas turbines tend to be considerably less capital-intensive than hydropower. In this context, it is important to note that, in the joint IIASA/WEC study, specific investment costs are different for domestically manufactured generating technologies and for technology imports. Conventional plant and equipment are assumed to be largely of domestic origin and thus carry a lower price tag than the comparable equipment in the OECD; the costs of more complex plant are essentially uniform across the regions.

The order of magnitude differences in the upstream sector investment volumes arise from the large net fossil exports from the DCs primarily to the OECD, as well as the construction of an elaborate natural gas infrastructure. By the year 2020, net exports range between 660 mtoe and 1,050 mtoe (the latter is approximately the 1990 volume), the bulk of which is Middle East oil exports. In addition, all developing regions accelerate oil and gas exploration over the coming 30 years, to meet growing domestic demand and to curb depletion of national income driven by oil imports. Several regions begin the development of capital-intensive, non-conventional oil reserves after 2010. A considerable amount of capital is absorbed by the expansion of energy transmission and distribution infrastructures.

## 2.5 Energy taxes and regulation

The Case C scenarios deserve a special mention, because of the regulatory measures (e.g. taxes) they incorporate to accelerate energy intensity improvements and to limit carbon emissions; this does not mean that new energy taxes would not be needed in other cases, but, in Case C, they are imposed explicitly. This gradually increases the real cost of energy to consumers by approximately a factor of four between 1990 and 2050. Tax revenue from the OECD region is transferred to the developing countries, and revenue from developing countries is recycled internally. The transfer of resources to the South results in a reduction in economic growth in the North. However, the potential impact of energy taxes is much larger in the South. First, the capital infusion from the North is not enough to offset the higher real cost of energy. Secondly, the impact depends on how productively tax revenue can be used. Taken together, these effects cause the 1990–2020 economic growth rates in Case C to fall behind those in Case A. However, in the longer run (post 2050), the transfer of funds to the South leads to GDP growth rates in Case C that exceed those in Case A. In the end, Case C's GDP in the South approaches that of Case A, and, in any case, is substantially higher than in the non-cooperative Case B. This hypothetical case illustrates that capital transfers from energy tax revenue could, in principle, be used for easing capital shortages in the developing countries, but that it requires an unprecedented degree of international cooperation. The relationship between energy regulatory and tax policies and investment is an important issue for the future assessment of energy financing requirements.

## 3. Conclusions

For all scenarios, the capital requirements of the energy sector are extremely large, but not infeasible. The good news is that investment requirements are likely to expand at a slower pace than overall economic growth. But there are two pieces of bad news. First, the energy sector will have to raise an increasing fraction of its capital from the private sector, where it will face stiffer competition and return on investment criteria than it has in the past. Secondly, most of the investment that needs to be made is in the developing countries, where current trends in the availability of both international development capital and private investment capital are not auspicious. The longer-term prospects of overall economic growth outpacing energy capital requirements are no reason for complacency. The most difficult investment challenge is usually the next power plant, pipeline or refinery. Unlike energy resource requirements, where uncertainty and potential difficulties are of a longer-term nature, capital requirements and finance need to be addressed and dealt with now. Today's investment will shape the immediate future, as well as the long-term options.

**References**


1. *World Energy Council, Global Energy Perspectives to 2050 and Beyond, WEC, London, UK, 1995.*

2. *World Energy Council, Energy for Tomorrow's World — The Realities, the Real Options and the Agenda for Achievements, Kogan Page, London, UK, 1993.*

3. *Bos, E., M.T. Vu, A. Leven and R.A. Bulatao, World Population Projections 1992–93, Johns Hopkins University Press, Baltimore, US, 1992.*

4. *World Energy Council, New Renewable Energy Resources: a Guide to the Future, Kogan Page, London, UK, 1994.*

5. *International Monetary Fund, International Financial Statistics, Washington, US, 1995.*

6. *Churchill, A.A., Energy Financing 1994 — New Directions and Perspectives, paper presented at the EuroForum Conference, The New World of Energy Financing, 8–9 February, London, UK, 1994.*

7. *Hanke, T., Die Märkte spielen verrückt, Die Zeit, Nr. 18:33, 1995.*

8. *Hyman, L.S., 1994. Financing Electricity Expansion, World Energy Council Journal, July 1994, 15–20.*

9. *Messner, S., and N. Nakicenovic, A Comparative Assessment of Different Options to Reduce $CO_2$ Emissions, WP-92-27, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1992.*

*10. Nakicenovic, N., and A. Grübler, Diffusion of Technologies and Social Behaviour, Springer Verlag, Berlin, Germany, 1991.*

*11. MacGregor, P.R., C.E. Maslak, and H.G. Stoll, The Market Outlook for Integrated Gasification Combined Cycle Technology, General Electric Company, New York, US, 1991.*

*12. Christiansson, L., Diffusion and Learning Curves of Renewable Energy Technologies, Working Paper, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1995.*

*13. Grübler, A., and N. Nakicenovic, Long Waves, Technology Diffusion and Substitution, RR-91-17, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1991.*

*14. Grubb, M., M. Koch, K. Thomson, A. Munson and F. Sullivan, The Earth Summit Agreements: a Guide and Assessment, The Royal Institute of International Affairs and Earthscan, London, UK, 1993.*

*15. World Energy Council, Financing Energy Development: The Challenges and Requirements of Developing Countries, WEC, London, UK, 1995.*

*16. Intergovernmental Panel on Climate Change, Second Assessment Report, forthcoming from Working Group I, Geneva, Switzerland, 1996.*

## APPENDIX

### Short description of the three cases

**Case A** (High Growth) is characterised by enormous productivity increases and wealth. It is technology- and resource-intensive and presumes favourable geopolitics and free markets. High growth facilitates a more rapid turnover of capital stock and changes in economic structure, both of which spur efficiency improvements and technological progress. If Case A is extended all the way to 2100, global average per capita income surpasses even the highest levels observed today and current distinctions between "developed" and "developing" regions become obsolete. Case A includes three scenarios, addressing alternative key developments in energy supply. In the Al scenario, there is ample future availability of oil and gas resources. At the other end of the spectrum, the A2 scenario assumes oil and gas resources are more limited, resulting in a massive return to coal. Finally, in the A3 scenario, rapid technological change in nuclear and renewable energy technologies results in a phase-out of fossil fuels, for economic reasons rather than due to resource scarcity. This unfolding into three different development trajectories results in three scenarios with almost identical energy end-use patterns but different energy system structures.

**Case B** (Middle Course), with a single scenario, is based on a more cautious approach, regarding economic growth prospects, rates of technological change and energy availability. In short, the scenario is, perhaps, best characterised by "modest dynamics" and derives its appeal primarily because it is "pragmatic." Overall, the Case B scenario is "reachable", without relying on drastic changes in current institutions, technologies or current perceptions of the availability of fossil fuel resources. The more modest energy use, compared with Case A, implies that scenario B can rely on fossil fuel resources to an extent that is commensurate with current estimates of ultimately recoverable oil and gas reserves. Energy supply and end-use patterns are also closer to the current situation for a longer period in Case B than in Cases A and C. Beyond 2020, however, the depletion of fossil resources, without counterbalancing technological progress, will force more dramatic changes in energy supply structures. Nonetheless, a transition away from fossil fuel use is feasible and manageable. In the very long term, the changes become much more dramatic, and an orderly transition away from fossil fuel use is not only feasible but appears to be manageable, in terms of energy sector and institutional adjustments extending towards the end of the 21st century.

**Case C** (Ecologically Driven) presents challenging global perspectives. It is optimistic about technology and geopolitics, but it also assumes unprecedented and aggressive international cooperation focused explicitly on environmental protection. It builds on substantial resource transfers from North to South, spurring growth in the South that will lead to a significant reduction in present economic disparities. In addition to stringent control of local and regional pollutants, a global regime, to control the emissions of greenhouse gases, is established. The goal is to reduce $CO_2$ emission levels to two GtC by the year 2100 [corresponding to one-third of 1990 levels required to stabilise atmospheric concentrations[16]]. Ambitious policy measures accelerate energy efficiency improvements and develop and promote environmentally benign, decentralised energy technologies. One policy option considered for achieving this goal is a carbon tax that gradually increases to $400 per tC in the year 2100. Case C describes a transition away from the current dominance of fossil fuels towards a dominance of renewable energy flows. The quality of the energy carriers delivered to end-users is high, in order to meet the environmental constraints, so that renewable energy sources are transformed into electricity, liquid and gaseous energy carriers. Nuclear energy is at a crossroads and this constitutes the main difference between the two Case C scenarios.