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TOPIC REPORT IV.: NATIONAL RTD ACTIVITIES AND SCOPE FOR EU INTERVENTION

EXECUTIVE SUMMARY

The objective of this part of the project was to analyse trends in energy R&D in the EU countries, both in terms of budgets and activity areas, and to identify areas in which EU intervention would offer benefits of scope or scale according to the principle of subsidiarity.

For this purpose, ad hoc qualitative and quantitative information on the energy RTD effort at the national level (both public and private) was collected through the organisations participating in the project. This in turn was elaborated and integrated with information supplied by existing studies and statistical databases (such as the EUROSTAT and IEA surveys on energy R&D budgets).

Obtaining quantitative and qualitative information on private sector RTD activities, which was an important goal for this part of the project, has been possible only in part, due to withholding of the information by the private industries for commercial reasons. This makes it difficult to draw meaningful conclusions on RTD trends in the private sector. On the other hand, the evidence collected on energy RTD budgets by EU governments and the European Commission is sufficiently robust to identify trends at least at the aggregate level.

OBSERVED TRENDS

From the analysis of the information collected some elements stand out.

Public budgets

Total government expenditures for energy R&D by the 15 EU countries (plus Norway) in the period 1983-93 show a considerable decline, both in current and in constant money terms. This negative trend contradicts the growth, both in current and in constant money terms, that can be seen in overall government R&D budgets. Energy R&D has dramatically decreased both as a share of total public R&D and in terms of ECUs per 1,000 ECU of GDP.

Although precise statistic correlations have not been computed during this analysis, the following qualitative considerations can be made concerning the factors that negatively affected energy R&D expenditures:

- a considerable portion of this decrease can be explained by the downsizing of the nuclear fission programmes and of related research efforts especially in Germany, the United Kingdom and Italy (where the nuclear programme was stopped altogether), after 1984 and especially in the aftermath of the Chernobyl accident. However, if trends outside the EU are also considered, a tendency to reduce budgets for nuclear fusion to what is strictly necessary to implement the preparatory work for the ITER project has emerged in recent years;
- the oil price collapse in 1985-86 and the persistence of relatively low prices in the oil market had a depressing effect on overall energy R&D budgets. At the beginning the impact may have been stronger on nuclear fission technologies (because it was combined with the negative effect of Chernobyl), while non-nuclear technologies (and, marginally, fusion) seem to have been affected harder at a later time;
- the need to harmonise the European economies towards lower inflation and smaller government deficits, brought along policies of government budget containment or outright reduction, which did not fail to affect energy R&D budgets;
- the Europe-wide trend towards privatisation of state-owned utilities and oil/gas/coal industries, which gained momentum after 1988, is likely to have affected, both directly and indirectly, the size and scope of government-funded energy research;
- finally, in the period considered, some technologies have reached maturity (this is partly the case for nuclear fission) or a commercial stage (e.g. wind power), needing mostly money for demonstration and dissemination

activities, while others have proved to be not viable (e.g. wave energy), explaining some decreases in related R&D budgets.

If the period 1990-95 is considered, the decrease in the R&D budgets of EU governments has been slightly faster for non-nuclear energy technologies than for nuclear (fission & fusion) energy technologies.

EU government funding of total energy R&D in 1994-96, after a long fall, may have reached a plateau. Considering only non-nuclear energy technologies, public funding in real terms is decreasing or at best stable.

Currently, the relative shares of nuclear and non-nuclear energy R&D over total EU governments budgets are around 58-60% for nuclear and respectively 42-40% for non-nuclear energy. If compared with the breakdown of total primary energy requirements for the whole of the European Union, this allocation of resources results are different from current reality. Of the total EU government budgets for nuclear energy, about 28% goes to fusion research.

Currently, government budgets for non-nuclear energy R&D are allocated as follows:

- *Rational Use of Energy (RUE)* represents 41%;
- *Renewables* represent 33-36%;
- *Fossil fuels* represent about 21%.

If the same budget is divided between energy supply technologies and energy end-use technologies, it seems clear that national governments pay a lot more attention to energy supply, which receives 68-70% of total resources, rather than to the energy demand side, which receives 30-32%.

These, however, are only average shares and reflect the allocation of the overall budget of the 15 EU countries considered. Wide differences exist concerning the areas of greater interest at the national level: these depend on climatic conditions, resource endowment, industrial base, and comparative advantage in the international economic system.

- Countries that devote more than the EU average to RUE R&D are Austria, Belgium, Denmark, Finland, Italy and Sweden.
- Countries that devote more than the EU average to renewables R&D are Germany, Greece, Italy, The Netherlands, Portugal and Spain.
- Countries that devote more than the EU average to fossil fuels R&D are France, Greece, Norway, the UK and, marginally, Portugal.

Budgets tend to focus more on the really promising areas. Government funding is increasingly becoming the only source of financing for some technological areas that either have not reached a commercial stage (many renewable energy technologies), represent only niche markets, or are being pushed out of the market (some technologies for the use of low-quality coals and peat, etc.). However, in many cases a shift towards short-term research in government budgets has been noted.

Concerning energy R&D budgets by the European Commission, the prevalence for funding nuclear energy (fission + fusion + radioactive waste & decommissioning) is absolute: 81% in the period 1989-90 and 76% in the period 1993-94. Within nuclear technologies, about 66% of resources go to fusion research. It is hardly necessary to remind the reader that fusion technology will not contribute towards energy security or global climate concerns for another 40-50 years, assuming plasma ignition is successfully achieved.

More recently EC funding for renewables and RUE seems to be increasing, while funding for R&D on fossil fuel technologies is falling. Less than 1% of the resources are devoted to general, cross-cutting technologies. In EC budgets, therefore, the preference for energy supply technologies is even stronger than in national budgets.

EU funding, however, appears to have a strong propulsive role in the national R&D programmes of countries such as Spain, Portugal and Greece.

Private budgets

The wave of privatisation in the energy industry is causing RTD budgets to fall in the privatising companies but data on overall private budgets are insufficient to determine whether this is a long-term or a temporary phenomenon.

Private investment for R&D seems to be particularly strong in the oil and gas industry and in power generation, but the focus has shifted towards short-term research. The interest in renewables appears to be relatively weak. In general, research efforts are concentrated on incremental improvements in the performance of plants/processes and products in terms of costs, reduced emissions or efficiency gains.

Research done in collaboration with IEA countries, under the framework of the IEA Implementing Agreements (IAs), in a situation of decreasing R&D resources, may have an increasing role not in quantitative terms (budget cuts are also taking place in the activities of the IAs) but rather in promoting synergies and collaboration.

ISSUES

The facts reported above seem to outline a few macro trends with some important implications which deserve to be discussed.

- There is an emerging differentiation among EC, national governments and private industries concerning their roles in R&D funding (i.e. what type of research they fund). The differentiation runs along the lines long- *vs.* short-term research rather than along the traditional split between basic *vs.* applied research. This distinction is not an idle one. Basic research does not usually give short-term results, but applied research can be very long term: fusion research is one such case of very long term and high risk applied research, especially considering that some basic theoretical problems have not yet been solved.

So far the EC seems to have favoured financing mostly long-term, high-risk applied research on fusion energy or inherently costly applied research for nuclear fission (specific components, safety-related aspects, radioactive waste and decommissioning).

At the other end, the role of the private sector in mature, commercial technologies and its preference for short-term, fast payback research is confirmed. Meanwhile, increasing shares of our energy systems are becoming private, and adopt a short-term view in research.

National governments are also becoming more oriented towards short-term research, but maintain strong roles both in some long-term, high-risk activities and in areas where a specific “vocation” or a comparative advantage for the country has emerged. *Should the trend towards more short-term research be confirmed in future years in both private and national governments budgets, who will carry out basic research?*

- Concerning the preference granted to nuclear technologies in the EC programmes, it is important to underline that while fusion research addresses very long-term energy needs, the type of research currently carried out on fission addresses mostly safety and security concerns, including those related to nuclear proliferation (which is also true in part for fusion research), rather than energy supply. Although nuclear fission and fusion R&D are outside the scope of the SENSER project, perhaps the balance between long- and short-term research, as well as the balance between basic and applied research, should be reconsidered at EC level, in terms of portfolio of technology options.

- As already stated, lack of information on the R&D spending and activities of the private sector, for reasons of commercial secrecy, is a fact we may have to live with but it weakens the robustness of our conclusions.

- Another important issue stems from the intrinsic limitation of classifications used in our statistics to identify and measure R&D efforts (both public and private). Just as good science is often interdisciplinary and stems from cross-fertilisation of ideas, it is often impossible to separate “purely energy technologies” from cross-cutting technologies having important impacts and implications on energy technologies and systems. In a great many cases the most relevant improvements in energy systems have originated outside of “energy research” (e.g. information technology, new materials, separation technologies, etc.). Furthermore, energy relevant R&D funding is in fact carried out by a large number of public institutions and by an even larger number of private firms not explicitly connected with energy (and especially energy supply) activities. A lot of military/defence-related (and thus “classified”) research has important energy implications. Therefore the picture usually outlined concerning the state of energy R&D is seriously incomplete, casting further shadows on the validity of the conclusions that can be drawn.

- A related issue concerns *what actually drives technology improvement in the energy sector: is it the level of energy R&D financial effort or the level of overall R&D effort?* Figures on total R&D spending by the public sector (national governments + EC) are still growing in nominal terms although they may be falling in real terms. If the overall R&D expenditure level is the main driver, the decrease in public energy R&D spending may simply be a reflection of the maturity reached by many energy technologies. In a great many cases the most relevant improvements in energy systems have originated outside of energy research (for example, information technology, new materials, separation technologies, etc.) and their diffusion throughout the economy was brought about for other purposes.
- Lacking sufficient information on the balance between public and private energy R&D and on the balance between energy research and research in other fields, we hesitate in concluding that the decrease in public R&D budgets for energy represents *per se* a negative and worrisome trend, although it may well be so. Certainly this trend needs to be put into the appropriate perspective and further analysed and explained. However, to minimise the risk of negative impacts of this trend on the well-being of future generations, efforts towards a rigorous prioritisation in the allocation of available resources should definitely be encouraged, and synergies in research should be better exploited.

RECOMMENDATIONS

From the analysis developed in this project, a few general recommendations can be made both to the EC and to the national governments.

1) Improve available information, both within the EU countries and within the EC, on the parties involved in energy R&D financing and R&D execution. This implies reconsidering classification systems in our statistics. This would have the added benefit of improved monitoring of energy and non-energy R&D.

2) Pay more attention (more systematic study and design of specific approaches) to <u>indirect</u> measures to support/encourage energy R&D funding and activities (e.g. economic, fiscal, regulatory measures).

3) Improve the energy R&D prioritisation process: this review process should be carried out for all energy technologies and cannot avoid the nuclear vs. non-nuclear issue (particularly current EC priorities on fusion).

4) Keeping in mind the *caveats* mentioned above, the areas where government-sponsored research or private investment may be needed or where the EC needs to refocus attention seem to be as follows.

   - <u>RUE in the transport sector</u>: here some low polluting technologies (electric and hybrid cars, fuel cell powered vehicles, new fuels) have not reached the commercial stage and need strong support. Furthermore, the system aspects of mobility, including infrastructure and social aspects, need increasing attention. Figures collected within the SENSER project on R&D budgets for this sector do not reflect the importance given to the transport sector from the energy and environmental standpoint. But this may be due to incomplete information. It is known that available data in many cases do not include RTD investments, sponsored by the Ministries of Transportation or by local governments, which have relevant impacts on energy consumption and efficiency. Also, private R&D by some car and vehicle manufacturers is known to be substantial, and the lack of attention towards this sector may be only apparent. But further collaboration in research and planning – if not increased spending – between government/public institutions and industry, as well as greater attention to non-R&D instruments, seem desirable in this sector.
   - <u>RUE in industry</u>: R&D in this area seems to have decreased but it is not clear whether this is only a false impression due to the different ways to classify energy-relevant R&D or a true lack of interest in this type of research by both industry and governments. Better focused programmes may be useful at least at the national level, for technologies and processes of potentially wide application, depending on country specific industrial structures. It also seems clear that in this field a combination of policy instruments, not just R&D expenditures, are required to improve energy efficiency in the industrial sector. Similar arguments hold for <u>RUE in the building sector</u>, where the limited gains in energy efficiency are due to structural (age and type of building stocks), behavioural and often regulatory obstacles.

- RUE in the energy industry: with privatisation of many electric utilities and the break-up of national monopolies in the energy networks (electricity, gas) also encouraged by EU policies, much R&D that was formerly carried out with direct government funding has now decreased or disappeared. Considering that within the EU electric power and gas demand will not increase dramatically (thus reducing the demand for new and more advanced production plants), while outside the EU, in developing countries, demand is directed towards proven and cheaper technologies, it is clear that demand for R&D in this sector will not be strong in the medium term. Probably the only way to support sustained R&D activity is for the governments (or the EU) to encourage (if needed with grants or other economic incentives) power and gas utilities to create consortia, together with energy systems manufacturers, for the purpose of carrying out joint research. The US EPRI example could be a useful model.
- Renewables: additional R&D efforts (at the pre-competitive or competitive level) seem necessary to improve the economics of renewable energy systems and to cut system/component production costs. This means devising appropriate measures to encourage research that can be carried out directly by the private industry and particularly by small and medium enterprises (SMEs). Research on grid-interfacing, and on regulatory, socio-economic aspects would also be beneficial.
- A more in-depth analysis and monitoring of the effort made on cross-cutting technologies (both within and outside the energy field) by the various EC (and national) programmes would be necessary to improve the returns of each ECU spent. But increased EC funding for selected clusters of cross-cutting technologies may also be desirable.

5) Under this framework, EU-sponsored research should make full use of available synergies and encourage co-operation between countries working on the same research areas. This does not exclude, in some cases, encouraging competition between different technological concepts for equivalent energy services/products. In other words, the idea of one “European technology” for energy systems and components, which has been adopted in a number of cases both within and outside the energy field, should not be the only philosophy driving EC energy R&D policy. First of all because this would discourage healthy infra-EU competition and create heavily subsidised monopolies. Secondly, this would have the undesirable implication of the EC taking sides for one specific technology and for one or more companies in a game which involves the interests of many European enterprises and national governments.

1. METHODOLOGY OF THE SURVEY AND CONSIDERATIONS ON THE QUALITY OF THE INFORMATION COLLECTED

1.1 OBJECTIVE

The objective was to construct a database of national energy RTD programmes suitable – together with the other information collected in this survey – to identify areas in which EU intervention would offer benefits of scope or scale in accordance with the principle of subsidiarity.

1.2 METHODOLOGY

To do so it was deemed necessary to build up a detailed qualitative and quantitative knowledge of the energy RTD effort at the national level, in order to enable the European Commission to identify areas where provision of EU funding would be beneficial and where it would not be needed. This information could then integrate the one supplied by several studies and statistical databases which already exist (e.g. the annual survey carried out by EUROSTAT on R&D budgets of the governments of the EU countries, and the IEA survey on energy R&D budgets of OECD countries), and give a deeper insight on this subject.

With respect to the information already available, extending the data to private sector RTD activities, which have generally not been covered in other surveys, was felt important, despite the difficulties of gathering relevant and detailed information from private enterprises.

Both **quantitative** and **qualitative** data were required from the national teams, according to predefined formats (tables) or guidelines.

A) Quantitative data

The first efforts required at the national level were:

- to update information on public (i.e. government) R&D expenditures to the years 1994 and 1995, and to include some estimate for 1996;
- to complement the data to include expenses by the private sector, by the EU and by other types of organisations for the same years.

Public R&D expenditures referred to all expenses made on energy R&D directly by national or local governments, through ministries, public research centres, or public universities.

Conversely, private R&D expenditures referred to all expenses made on energy R&D by private industry or by partly government-owned joint stock companies **operating under market rules** (i.e. active in the market under market laws and having independent decision power in the business). Difficulties were expected in collecting information on private R&D activities.

In parallel, an attempt was made to quantify at the national level the EU contributions for RTD activities, as well as the R&D expenditures made by other organisations that did not fall precisely in either one of the three previous categories.

The classification by research area adopted for this data collection was mainly based on the one introduced by DG-XII and DG-XVII and adopted in the JOULE-THERMIE programme, with some modifications and extensions. However, for the purpose of comparing the results for the three years considered with the longer time series of the IEA survey, a table was prepared enabling a rough "conversion" from the DGXII-DGXVII classification into the IEA classification and vice-versa.

Once collected and transferred to the Topic Leader, the data were "processed" using standard computer spreadsheets. Figures in national currencies were translated into a common unit (thousand ECUs) for aggregation and elaboration purposes. Percentages and indexes were computed to allow better interpretation of the information collected and the results organised in tables (see **Appendix** to this report).

In most output tables supplied, the disaggregation of the technology areas reached the two-digit level of the classification adopted for this project.

- Table A.1.1 shows public expenditures, by country in national currencies for the years 1994, 1995 and 1996.
- Table A.1.2 shows public expenditures, by country, in thousand ECUs for the same years.
- Table A.1.3 shows the shares of public expenditures for various technology areas over total public expenditures in energy RTD for each country. Within the main RTD areas (energy RTD strategy, rational use of energy, renewables, fossil Fuels) percentage shares of the various sub-areas are also indicated.
- Table A.1.4 shows the shares of each country's expenditures in any given technology area over the total EU-14 expenditures in the same technology area.
- Table A.1.5 gives for each country and year a sort of "specialisation index" built as the ratio of the shares shown in table A.1.4 to the share of a country's energy R&D budget over the total EU-14 energy R&D budget.

Data collected on private expenditures are incomplete: around only half the countries involved in the project were able to supply information on this subject, therefore the indexes reported in tables A.2.4 and A.2.5 are not very meaningful and should be viewed with caution.

- Table A.2.1 shows private expenditures, by country in national currencies for the years 1994, 1995 and 1996.
- Table A.2.2 shows private expenditures, by country, in thousand ECUs for the same years.
- Table A.2.3 shows the shares of private expenditures for various technology areas over total public expenditures in energy RTD for each country. Within the main RTD areas (energy RTD strategy, rational use of energy, renewables, fossil Fuels) percentage shares of the various sub-areas are also indicated.
- Table A.2.4 shows the shares of each country's private expenditures in any given technology area over the total EU-14 expenditures in the same technology area.
- Table A.2.5 gives for the private expenditures of each country and year a sort of "specialisation index" built as the ratio of the shares shown in table A.1.4 to the share of a country's energy R&D budget over the total EU-14 energy R&D budget.
- Finally, Table A.3 shows the total public and private RD&D expenditures of the EU countries (14 of them are included in the columns on public budgets, while only 9 are included in the columns on private budgets), for the years 1994, 1995 and 1996, at the highest level of detail (four-digit level classification).

The formula used for the "specialisation indexes" in tables A.1.5 and A.2.5 is the following:

$$^{1994}SI_{ij} = ((^{1994}x_{ij} / \Sigma_j\ ^{1994}x_{ij})/((\Sigma_i\ ^{1994}x_{ij})/(\Sigma_i\Sigma_i\ ^{1994}x_{ij}))) * 100$$

where $^{1994}SI_{ij}$ is the "specialisation index" of country j in the i-th technology area (e.g. RUE in industry) in 1994 and $^{1994}x_{ij}$ is the R&D expenditure of country j in the i-th technology area in 1994.

This is a rough indicator of whether any given country spends in R&D for the i-th technology area a larger or smaller proportion than the share of that country's total energy R&D budget over the total EU-14 energy R&D budget. For example if the Austrian share of R&D expenditures on RUE in industry over total EU expenditures on RUE in industry equals 5.9% in 1994, and the total Austrian energy R&D expenditures represent 3.5% of the total EU-14 energy R&D budget in the same year, our index will be equal to:

$^{1994}SI_{2.2AT} = (5.9/3.5)*100 = 166.5$

Thus an SI > 100 indicates an expenditure level in a given R&D area greater than the percentage country contribution to the overall energy R&D expenditures of the EU countries. Conversely, an SI < 100 indicates an expenditure level in a given R&D area smaller than the percentage country contribution to the overall energy R&D expenditures of the EU countries. Notice that:

$^{1994}SI_{ij} = ((^{1994}x_{ij} /\Sigma_i \, ^{1994}x_{ij}) /((\Sigma_j \, ^{1994}x_{ij})/(\Sigma_i\Sigma_i \, ^{1994}x_{ij}))) * 100$

and therefore it also represents the ratio of a country's expenditure share in a given technology area and the overall expenditure share for the EU-14 countries on the same technology area.

It is necessary to stress that this is only a rough indicator of a country's "specialisation", "preferences" or "priorities" in RTD expenditures. Furthermore it must be borne in mind that this indicator is only as good as the underlying figures for that country and the other EU countries R&D expenditures. In other words its quality depends on the quality and completeness of the estimates of the variables involved.

B) Qualitative data

Qualitative information on RTD activities at the national level was requested together with the data on RTD budgets. In particular:

- for each main line of RTD activity, the main organisations and agencies funding energy research;
- for each main line of RTD activity, indications on the content and objectives of the activity, timescale, long-term strategic research *vs.* short-term research, role of different parties (industry, academia, government);
- trends and technical reasons of RTD choices;
- identification of the main agencies, universities and laboratories performing the research.

1.3 COMMENTS ON THE QUALITY OF THE INFORMATION COLLECTED

Concerning the above aspects of this research, country reports have different degrees of detail and information, both for the qualitative and quantitative sections. Respondents often did not utilise the standard formats indicated by the topic co-ordinator.

Quantitative data in most cases are limited to government budgets and in some cases did not cover (even as provisional data) the year 1996. Only nine countries were able to supply information on the budgets of the private sector, as this is generally considered by the private businesses to be proprietary or confidential information. Only two countries were able to supply data on EU contributions. The results of this survey are given in Chapter 3 of this report. Summary tables for public and private RTD budgets, in national currencies and ECUs, are supplied in the Appendix.

The qualitative elements are particularly not homogeneous. Not all cases include sufficient detail as to the content of the research activities. Another aspect which is generally missing is the explanation of why a certain RTD is being followed, or is not being followed, or has been abandoned.

A compilation of the qualitative aspects of the national RTD activities summarised in the country reports is given in Chapter 4 of this report. In some cases only the relevant titles of research lines are reported, giving an indication of the content of the research. In other cases, what is reported as a title is all that is available – and sometimes it gives no indication of the content. In other cases, not even a title is given.

2. TRENDS IN RTD EXPENDITURES IN THE PERIOD 1983-93

The information provided in this section summarises the trends in energy RTD expenditures and in overall RTD expenditures by the EU governments and the Commission of the European Communities, emerging from two other sources: the yearly survey carried out by EUROSTAT and the IEA survey on energy R&D budgets.

Methodology and classification rules differ between the two surveys and with respect to the one carried out by the SENSER project. This makes comparisons among the three surveys and their results basically impossible. What is expected by a review of these other data sources is a two-fold result.

1) to seek external support from other information sources concerning the order of magnitude of the main aggregates that form the total energy R&D expenditures of the EU governments and to indirectly assess the robustness of the results of the SENSER project;

2) to place the results of the short-term survey conducted within the SENSER project in a longer time frame, thus separating long-term trends from short-term fluctuations. For this reason the period analysed covers the years from 1983 to 1995.

2.1 THE EUROSTAT SURVEY

EUROSTAT data on government R&D budgets in EU countries are reported in the yearly publication "Government Financing of Research and Development". Additional data on the government budgets of some EFTA countries (Austria, Finland, Norway, Sweden) were published in the "European Report on Science and Technology Indicators 1994" by the European Commission.

The EUROSTAT survey groups government R&D expenditures into 13 broad categories according to the NABS classification: one of them is "Production, distribution and rational utilisation of energy". These categories, in turn, are broken down into various subclasses. The NABS classification has changed and has been widened over time, giving rise to problems of breaks in the time series, but the period we are concerned with is wide enough to include seven major technological areas (General research, Fossil fuels and their derivatives, Nuclear fission, Nuclear fusion, Renewable energy sources, Rational utilisation of energy, Other research on production, distribution and rational utilisation of energy). Unfortunately many countries report only aggregate expenditures for energy R&D; furthermore, as membership to the EU has increased from 1980 up to now, continuous adjustment in the data set has been necessary, which suggests caution in its use.

Total government expenditures for energy R&D by the 15 EU countries (plus Norway) in the period 1983-1993 show a considerable decline. Values expressed at current prices and exchange rates of the year fall from 3,120.4 million ECU in 1983 to 1,921 million ECU in 1993, that is, at an average rate of decrease of 4.7% per year (table 1). If values are expressed in constant terms (at 1985 prices and Purchasing Power Standards - PPS) the fall is even more dramatic: from 3,294.1 to 1,418.6 million ECU, with a rate of decline of 8.1% per year (see Table 2 and Figure 1). Government budgets for energy, however, grew from 1983 to the following year and started their staggering descent after 1985, in remarkable coincidence with the fall of world oil prices.

A synthetic representation of the corresponding trends in the various countries is given in Figure 2, where government energy R&D expenditures (in real terms) at the beginning of the period (average 1983-85) are compared to expenditures at the end of the period (average 1991-93).

Figure 3 shows, for the same period, government energy R&D expenditures (in real terms) in ECU per 1,000 ECU of GDP in the various countries. Again, this indicator shows a clear decrease in government attention for energy R&D.

Among the 15 countries considered, those with the largest government budgets are Germany, France, Italy and the United Kingdom. However, while French budgets in 1993 had almost recovered after a decline in 1986-90, the British and Italian budgets in nominal terms had become nearly one third of what they were in 1983 and the German budget had halved with respect to 1983. Other countries showing a clear decrease in their energy R&D

budgets are Belgium, Sweden and Spain. The Netherlands maintained a fairly stable level of expenditures throughout the period. Most of the remaining countries show a constant or increasing trend (at least in current money terms) in their budgets.

These differences in behaviour among countries suggest that the reduction in energy R&D budgets is also strongly related to the difficulties of the nuclear programmes in Europe after the Chernobyl accident. Ongoing privatisation processes in the energy industry may have made these negative trends more pronounced.

In the same period total R&D expenditures by EU Governments at current prices and exchange rates grew from 29,441 million ECU in 1993 to 54,239 million ECU in 1993, that is an average rate of growth of 6.26% per year. The same expenditures expressed at 1985 prices and PPS amounted to 30,576 million ECU in 1983 and 40,405 million in 1993 (see figure 4). This increase corresponds to an average yearly rate of growth of 2.83%. It is apparent that trends in energy R&D and trends in total R&D not only diverge significantly but go in opposite directions.

Energy R&D expenditures by the European Commission expressed at current prices and exchange rates amounted to 330.7 million ECU in 1983, peaked in 1988 at 412.3 million and returned to 323.8 million in 1993 (333 million in 1994). In constant terms (at 1985 average prices) EC expenditures went from 370.6 million ECU in 1983 to 373.8 million in 1988 and then fell to 243.3 million in 1993. These figures, however, do not include the THERMIE demonstration programme (started in 1990), for a total value of about 700 million ECU over six years. In real terms, this might imply, at best, that the decrease in EC budgets seen in the period 1990-94 has not taken place and that EC budgets have remained roughly constant.

Thus the EC energy programme activities are playing an increasing role in overall European energy R&D but EC budgets have not been able to offset the substantial decreases in the largest EU government budgets.

The ratio of energy R&D expenditures made by the European Commission to the total public energy R&D (16 EU governments + EC) equalled 10.6% in 1983, grew to 20.2% until 1990, returned to 16.9% in 1992 and then increased again to an estimated 18-20% if the THERMIE programme is taken into account (see figure 5).

Figure 6 shows the diverging trends of total R&D and energy R&D budgets of the EC.

Concerning the breakdown of energy R&D expenditures made by the governments of the EU countries among the various technological areas, the information available from EUROSTAT is incomplete and fragmented. Desegregated data are available for only 7-8 countries (Germany, Greece, Ireland, Italy, the Netherlands, Portugal, Spain and United Kingdom) and therefore are of little use; furthermore data only cover the period 1989-94.

A breakdown of energy R&D expenditures, however, is available for the EC budget for the periods 1989-90 and 1993-94 (see figure 7).

As can be noticed, the prevalence of funding for nuclear energy (fission + fusion + radioactive waste & decommissioning) is absolute: 81% in the period 1989-90 and 76% in the period 1993-94. More recently, funding for renewables and for rational use of energy seems to be increasing, while funding for R&D on fossil fuel technologies is falling. These data, however, do not include expenditures for the THERMIE programme: if these were taken into account, in the most recent years the allocation of resources might look less slanted in favour of nuclear technologies.

More information concerning the expenditures breakdown among technology areas in the EU countries can be found in the IEA survey data.

Table 1.: Total government budget appropriations/outlays for R&D for production, distribution and rational utilisation of energy (NABS class: 5)

MECU at current prices and current exchange rates by country - years 1983 - 1994

	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
Austria	-	-	7.4	7.1	7.4	6.0	4.5	3.9	7.0	6.1	7.8	8.0
Belgium	59.7	72.8	74.7	66.4	64.6	61.5	27.2	28.5	30.0	30.0	31.4	34.0
Denmark	32.8	22.8	27.5	25.2	26.5	24.6	25.7	26.0	25.3	28.0	32.6	18.0
Finland	17.8	20.1	24.9	25.95	27.9	29.6	33.8	36.4	41.1	38.3	32.5	29.0
France	649.4	702.1	777.0	468.1	451.3	436.9	415.4	384.4	422.2	510.1	535.8	532.0
Germany	1.276.9	1.318.7	1.193.6	1.040.2	860.3	754.3	734.4	732.9	741.6	722.8	692.5	631.0
Greece	2.0	3.3	2.9	6.0	5.6	3.9	4.4	2.5	4.8	4.5	4.6	7.0
Ireland	2. 5	1.6	1.4	1.9	1.1	0.3	0,5	1.8	1.0	0.7	0.6	0.2
Italy	616.5	766.4	721.3	671.0	501.3	495.0	356.0	373.0	356.2	274.8	255.6	186.0
Netherlands	68.3	71.7	71.1	69.7	72.1	62.4	67.4	69.9	69.1	68.2	71.0	68.0
Norway	18.7	20.3	21.7	21.1	21.8	25.1	27.72	36.6	37.2	37.7	32.9	25.0
Portugal				4.2	3.5	2.5	5.6	7.7	11.2	10.7	13.8	11.0
Spain			63.9	85.3	28.9	30.5	54.8	55.4	54.8	46.0	42. 8	32.0
Sweden		112.3	119.1	99.9	87.9	85.5	75.8	75.0	68.2	58.5	44.0	49.0
United Kingdom	375.8	351.8	347.9	279.4	241.8	266.9	234.2	198.5	189.8	171.3	123.2	80.0
Total EU	3.120.4	3.464.0	3.454.4	2.871.5	2.402.3	2.285.0	2.067.4	2.032.3	2.059.4	2.007.8	1.921.0	1.710.2
E. C.	330.7	317.1	319.7	371.3	382.0	412.3	405.6	410.8	406.0	297.2	323.8	333.0

Table 2.: Total government budget appropriations/outlays for R&D for production, distribution and rational utilisation of energy (NABS class: 5)

MECU at 1985 prices and purchasing power standards by country - years 1983-93

	1983	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
Austria	-	-	8.0	6.9	6.9	5.6	4.2	3.5	5.9	4.6	6.0
Belgium	68.6	80.5	76.0	63.1	59.0	57.0	24.2	24.4	25.4	24.6	24.3
Denmark	30.9	19.0	21.7	18.5	18.2	16.6	16.9	16.6	16.5	17.5	25.3
Finland	0.0	17.4	20.1	20.9	21.5	20.2	20.4	21.0	24.2	23.9	23.3
France	708.9	714.1	731.3	410.2	388.9	374.3	349.0	312.4	344.8	398.7	415.0
Germany	1179.7	1214.4	1102.6	890.1	706.6	626.7	610.1	593.1	584.5	529.7	539.4
Greece	3.2	4.4	3.5	7.1	5.9	3.4	3.4	1.5	2.5	2.1	1.4
Ireland	2.6	1.5	1.2	1.7	1.0	0.3	0.4	1.6	0.9	0.7	0.5
Italy	835.7	901.4	786.5	655.4	456.5	424.7	279.6	266.7	234.3	177.3	156.3
Netherlands	62.4	66.2	66.1	63.8	66.3	58.6	64.8	66.4	64.2	61.1	63.5
Norway	0.0	14.6	14.9	17.1	16.9	18.3	18.6	24.5	24.9	26.6	22.9
Portugal	0.0	0.0	0.0	6.3	4.8	3.1	5.9	6.7	8.1	6.3	5.4
Spain	0.0	0.0	82.6	98.3	31.5	30.0	46.8	42.6	39.3	30.1	25.1
Sweden	0.0	101.1	97.7	78.9	68.2	60.2	46.8	43.1	34.0	27.3	28.1
United Kingdom	402.0	366.3	337.6	299.5	252.6	243.4	198.3	164.5	141.3	130.4	81.9
Total	3294.1	3500.8	3349.8	2637.7	2104.8	1942.2	1689.4	1588.7	1550.7	1460.7	1418.6
EC	370.6	332.4	319.7	360.1	361.4	373.8	346.7	334.0	317.4	225.1	243.3

Figure 1.

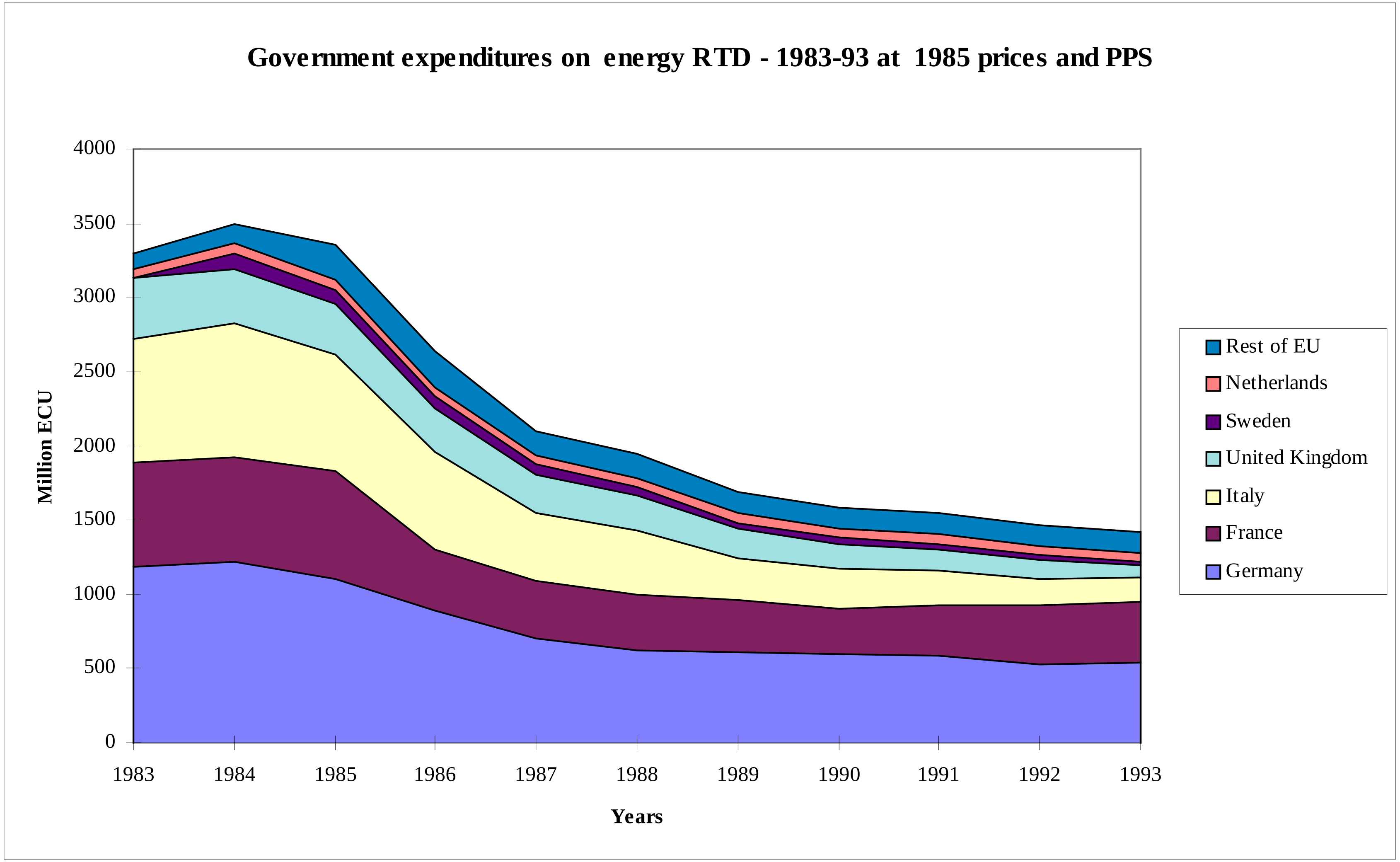

Government expenditures on energy RTD - 1983-93 at 1985 prices and PPS
Million ECU
4000
3500
3000
2500
2000
1500
1000
500
0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Years
Rest of EU
Netherlands
Sweden
United Kingdom
Italy
France
Germany

Figure 2

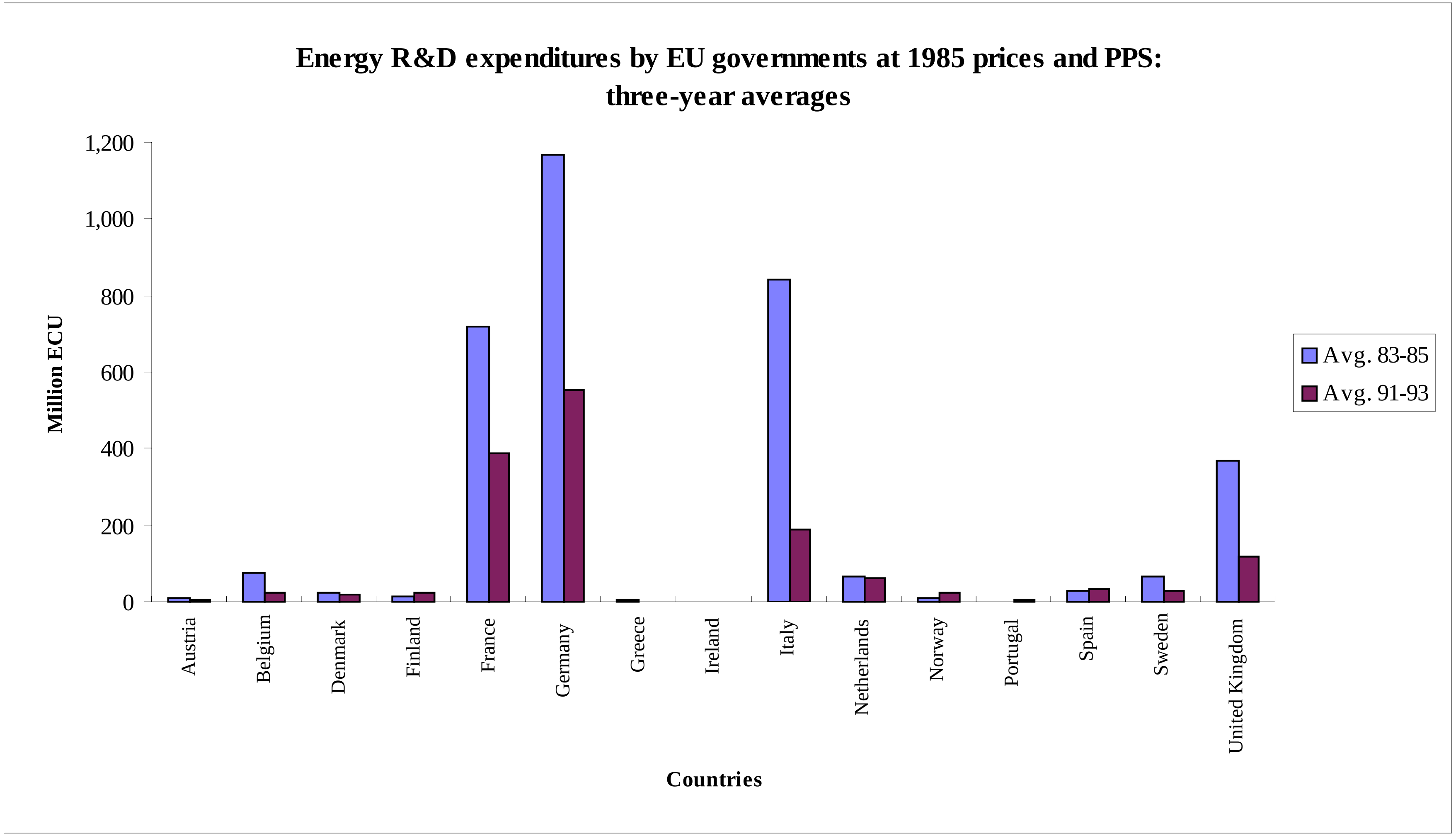

Energy R&D expenditures by EU governments at 1985 prices and PPS: three-year averages
Million ECU
1,200
1,000
800
600
400
200
0
Austria
Belgium
Denmark
Finland
France
Germany
Greece
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
United Kingdom
Countries
Avg. 83-85
Avg. 91-93

Figure 3

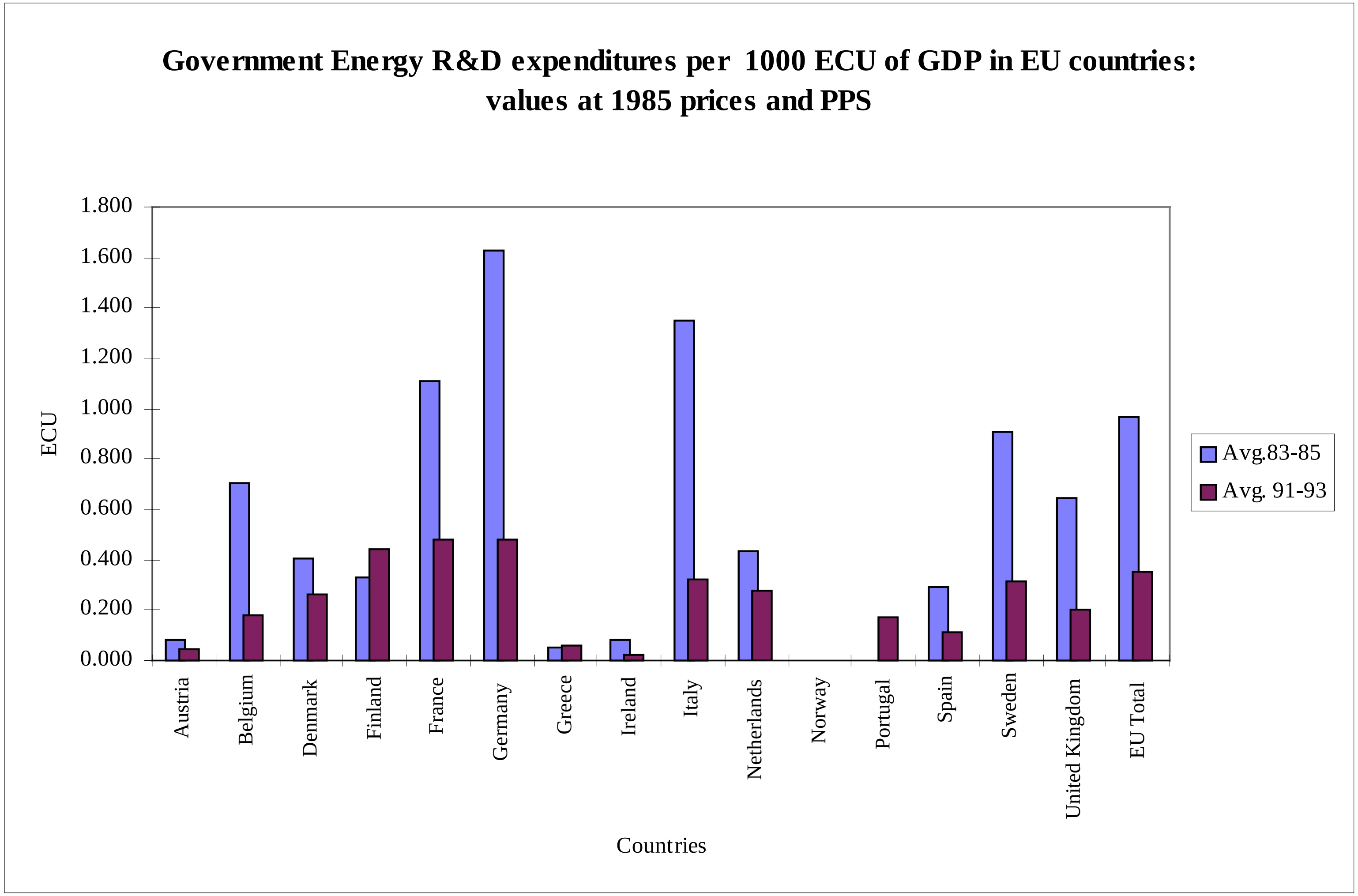

Government Energy R&D expenditures per 1000 ECU of GDP in EU countries:
values at 1985 prices and PPS
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
ECU
Austria
Belgium
Denmark
Finland
France
Germany
Greece
Ireland
Italy
Netherlands
Norway
Portugal
Spain
Sweden
United Kingdom
EU Total
Countries
Avg.83-85
Avg. 91-93

Figure 4

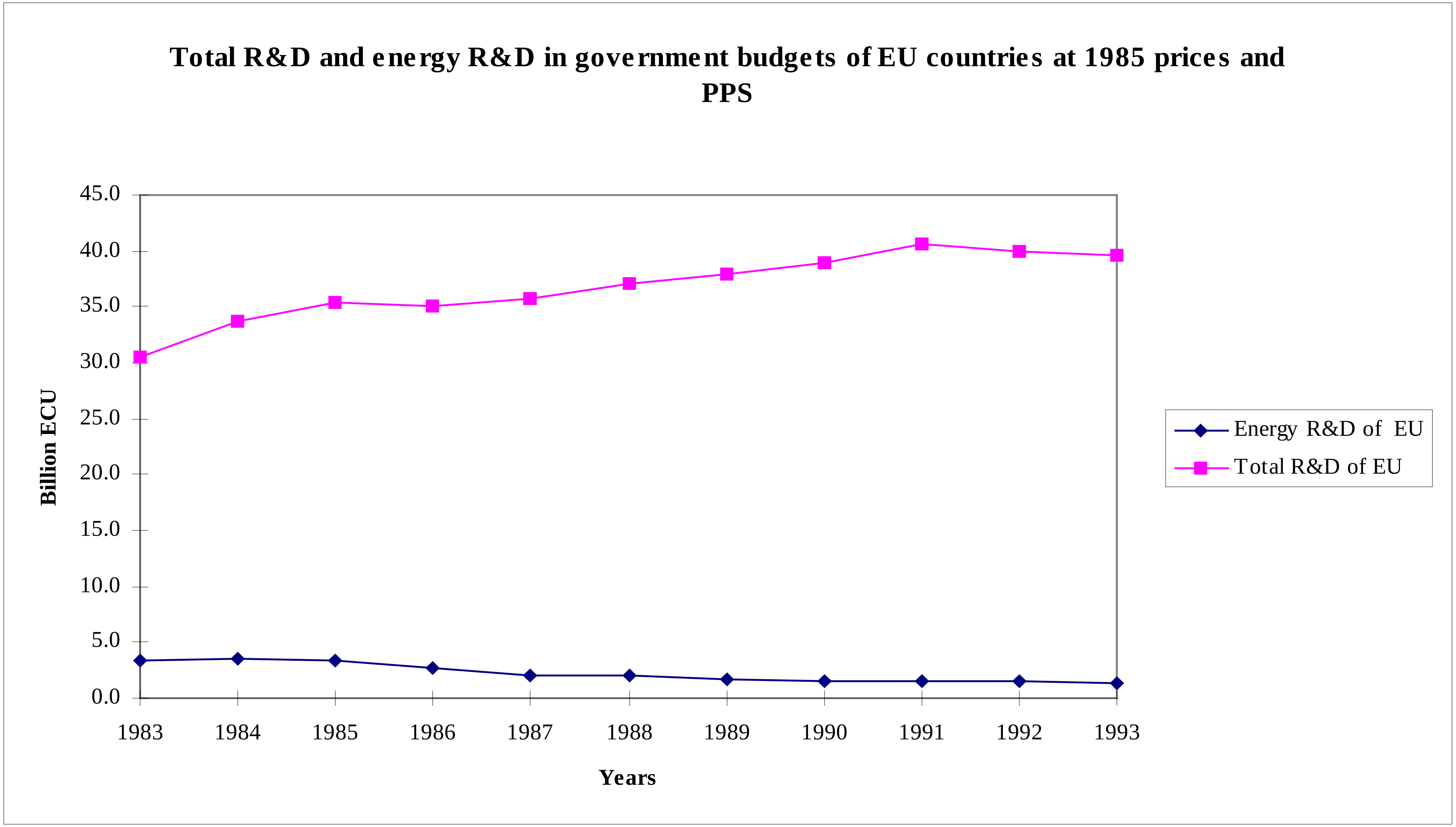

Total R&D and energy R&D in government budgets of EU countries at 1985 prices and PPS
Billion ECU
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Years
Energy R&D of EU
Total R&D of EU

Figure 5

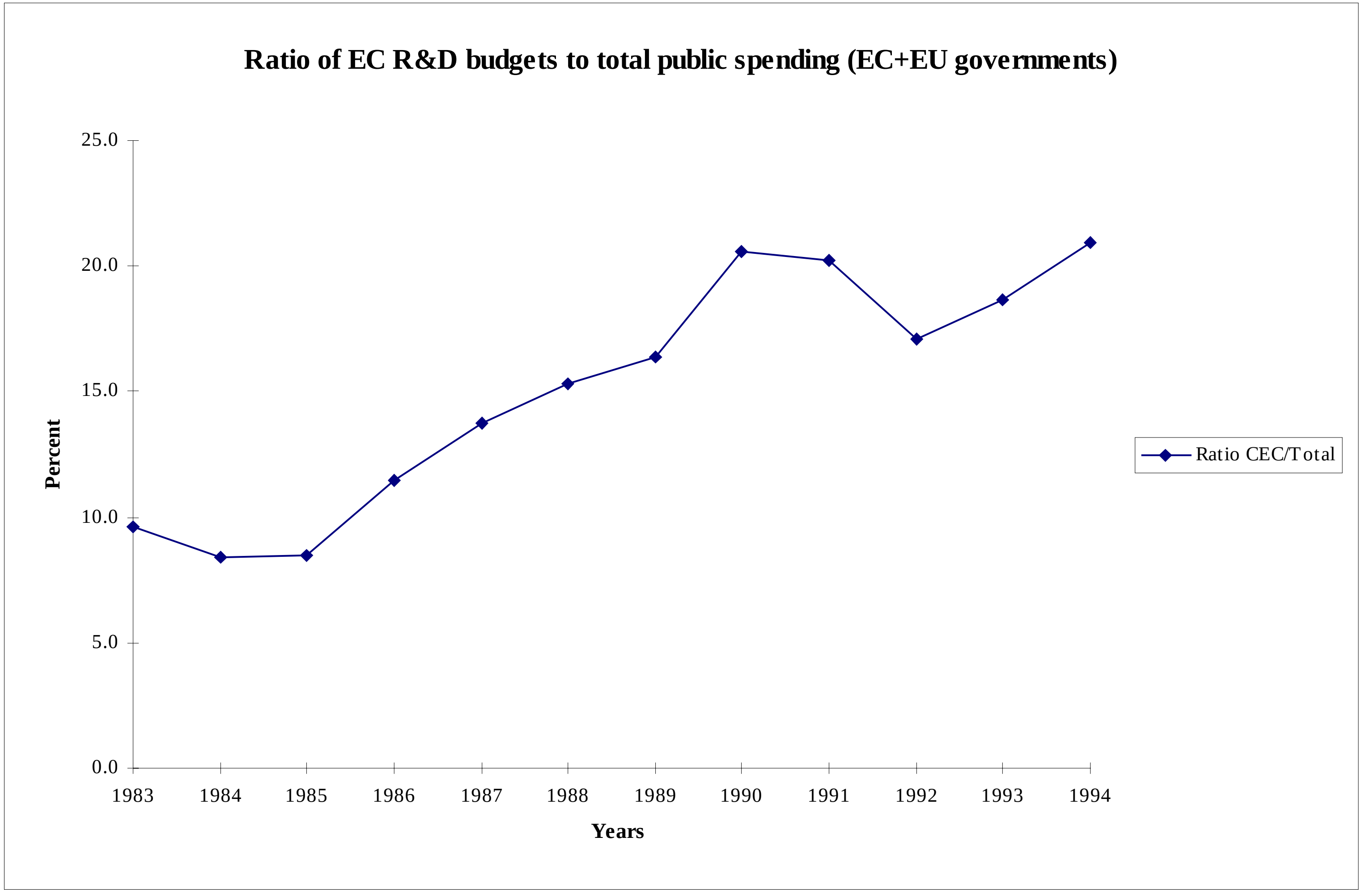

Ratio of EC R&D budgets to total public spending (EC+EU governments)
Percent
25.0
20.0
15.0
10.0
5.0
0.0
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
Years
Ratio CEC/Total

Figure 6

Total R&D and energy R&D budget of the EC at 1985 prices and PPS

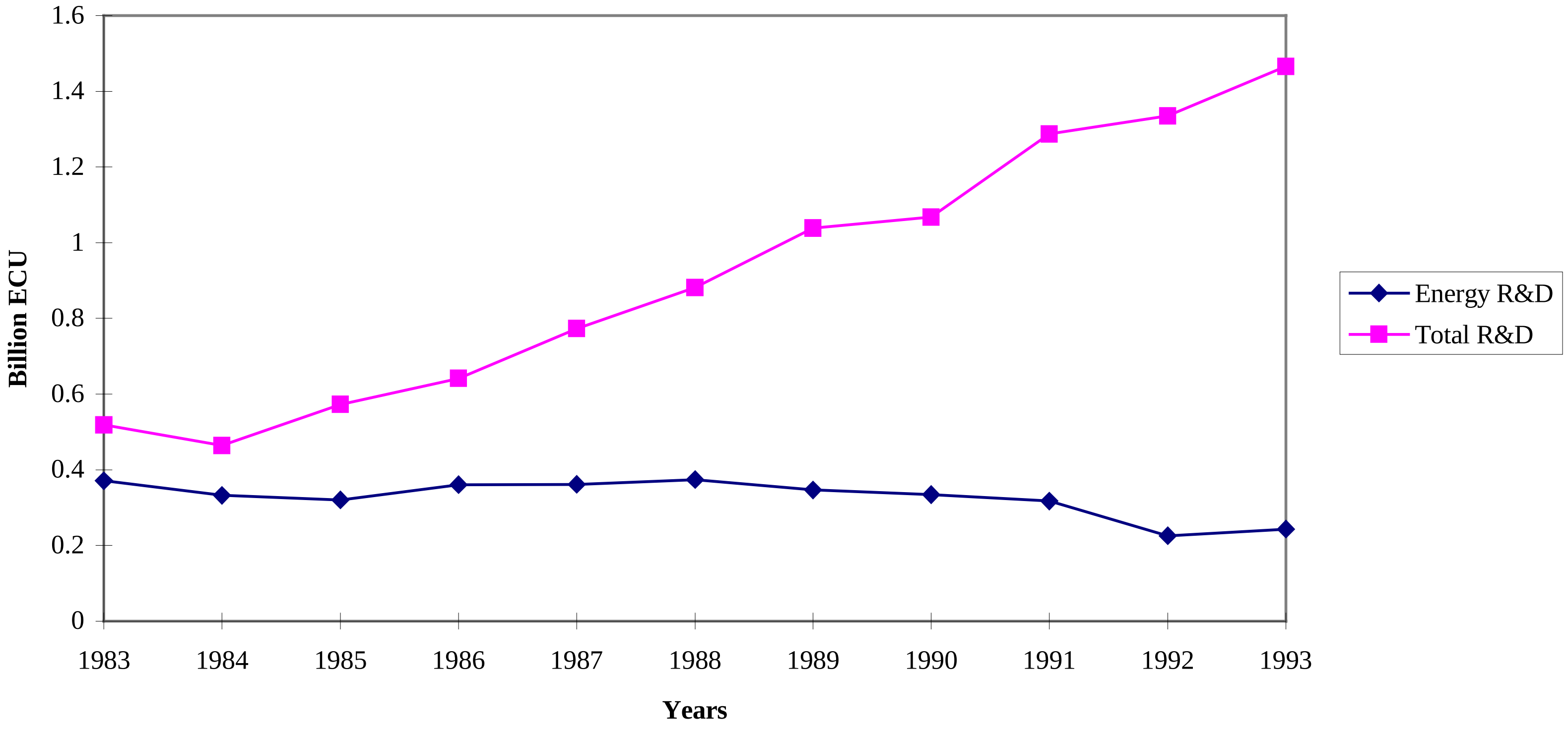
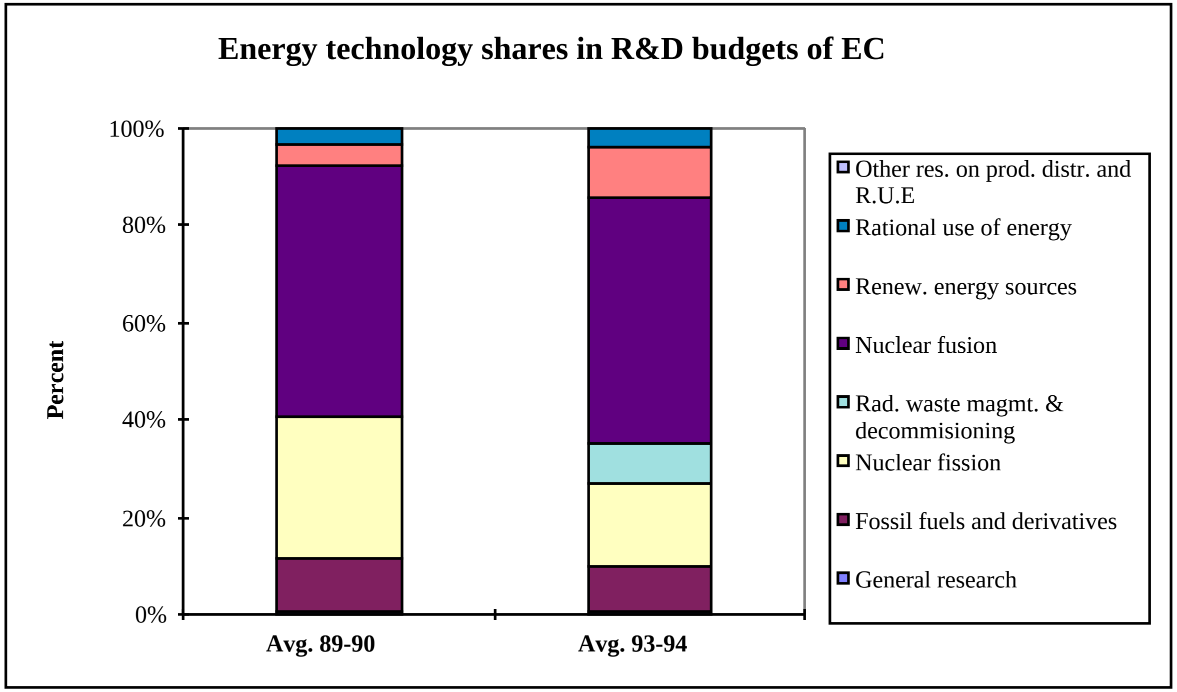


Figure 7


Energy technology shares in R&D budgets of EC
100%
80%
60%
40%
20%
0%
Percent
Avg. 89-90
Avg. 93-94
Other res. on prod. distr. and R.U.E
Rational use of energy
Renew. energy sources
Nuclear fusion
Rad. waste magmt. & decommisioning
Nuclear fission
Fossil fuels and derivatives
General research

2.2 THE IEA SURVEY

A fairly long series of data on government budgets for energy R&D in the IEA countries has recently been made available in the volume “IEA Energy Technology R&D Statistics 1974-1995” (1997). The volume contains data for the countries that are members of the International Energy Agency. As all EU member countries (plus Norway) are also members of the IEA, this alternative source of information can be used to complement our analysis of past trends in energy R&D budgets.

Like the EUROSTAT data, these also include R&D expenditures for nuclear energy (fission and fusion). Furthermore, the IEA survey offers a much wider disaggregation of data by fuel/technology area than does the EUROSTAT database. Potential advantages from this disaggregation had already been envisaged at the planning stage of the SENSER project. At that time the possibility of “translating” the IEA expenditure classification into the one used by the SENSER project and vice-versa had been explored and a sort of “synoptic table”, to help in this purpose, had been prepared. This preliminary work allowed the identification of a number of problems and inconsistencies in going from one classification methods to the other (e.g. areas of overlaps), which make the two data sources, strictly speaking, non-comparable. However, at certain levels of aggregation the two data sources not only give the same orders of magnitude but produce very similar results.

The trends shown by the IEA data (expressed in million US$ at 1995 prices and PPPs) depict a similar story to the one described by the EUROSTAT data: total R&D expenditures in EU countries are halved in the period 1983-93 and decrease still further until 1995.

The IEA data unfortunately are incomplete (include for every year of the period a number of EU countries that varies from 12 to 14 and every year a different set) and are technically non-comparable from one year to the next. Furthermore, data for France only started being included in 1990. Hence extra caution must be used in drawing conclusions from these data.

In order to overcome this problem, at least in part, and based on availability of data, total government expenditures for a set of 11 countries (Austria, Denmark, Germany, France, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, and United Kingdom) were considered for the period 1990-95 (see Table 3).

IEA data, expressed in 1995 US$, were then translated into ECU using current Dollar/ECU exchange rates (see Table 4).

Finally, based on the definitions of the technology areas used in the IEA survey, some strong assumptions were made concerning the correspondence between individual items of the IEA classification and the two-digit classification adopted by the SENSER project. This made it possible to reaggregate IEA figures according to the SENSER project and to compare the results (Tables 5, 6, 7, 8).

One initial remark that can be made is that government budgets for the 11 countries considered show a strong preference for the nuclear technologies (fusion + fission), which throughout the period 1990-95 take about 60% of total energy budgets, while non-nuclear technologies receive the remaining 40% (Table 5).

If, however, we limit the analysis to non-nuclear energy technologies, over this period we see an increasing interest for renewables (from 29 to 36%), a decrease in R&D for fossil fuel technologies (from 26 to 18%) while research on RUE obtains a share that fluctuates between 40% and 45%.

This overall picture can now serve as a basis for comparison with the results of the SENSER survey.

Concerning energy R&D expenditures made by private enterprises in EU countries, unfortunately data are not available or are so incomplete as to be of little use. All we know is that in the period 1990-95 overall R&D expenditures of private enterprises (including all technological areas) in the European Union have increased from 70.9 to 79.1 billion US$ (at current prices and PPP), (Source: OECD, *Main Science and Technology Indicators*, I/1997).

Table 3.: Government Energy R&D Budgets in EU Countries ***Million US$ - 1995 prices***

		1990	1991	1992	1993	1994	1995
1.1	Industry	109.52	120.06	102.31	107.85	80.10	76.72
1.2	Residential, Commercial	64.71	81.67	62.76	50.28	46.25	43.34
1.3	Transportation	57.16	45.18	54.87	53.79	47.47	44.81
1.4	Other Conservation	75.30	57.69	45.84	46.49	26.72	24.74
1.	**Total Conservation**	**306.69**	**304.60**	**265.78**	**258.41**	**200.54**	**189.61**
2.1	Enhanced Oil and Gas	26.19	14.73	21.42	33.10	38.07	34.60
2.2	Refining, Transport & Stor.	5.85	3.11	4.05	1.62	2.90	3.46
2.3	Oil Shales and Tar Sands	0.00	0.00	0.00	0.00	0.02	0.00
2.4	Other Oil & Gas	72.65	59.17	64.19	47.62	48.98	47.47
2.	**Total Oil & Gas**	**104.69**	**77.01**	**89.66**	**82.34**	**89.97**	**85.53**
3.1	Coal Prod., Prep. and Transp.	30.70	23.50	13.95	10.80	2.26	2.43
3.2	Coal Combustion	78.32	50.99	46.46	43.37	32.40	24.02
3.3	Coal Conversion	21.59	20.69	16.80	8.46	6.23	4.17
3.4	Other Coal	25.42	22.02	12.29	7.46	9.01	7.01
3.	**Total Coal**	**156.03**	**117.20**	**89.50**	**70.09**	**49.90**	**37.63**
	Total Fossil Fuels	**260.72**	**194.21**	**179.16**	**152.43**	**139.87**	**123.16**
4.1	Solar Heating & Cooling	42.86	45.16	44.26	44.20	34.30	30.02
4.2	Solar Photo-Electric	109.62	113.02	127.52	114.16	89.70	84.45
4.3	Solar Thermal-Electric	20.80	17.65	14.17	11.15	8.37	12.98
4.	*Total Solar*	173.28	175.83	185.95	169.51	132.37	127.45
5.	*Wind*	84.44	75.42	73.48	78.95	54.78	91.73
6.	*Ocean*	6.99	7.47	2.19	2.76	1.61	0.86
7.	*Biomass*	45.18	52.53	73.36	62.48	54.18	55.59
8.	*Geothermal*	19.77	17.40	9.37	9.92	6.56	4.08
9.1	Large Hydro (>10 MW)	0.00	4.09	3.96	4.30	4.24	2.68
9.2	Small Hydro (<10 MW)	0.00	0.64	9.47	0.72	0.35	0.46
9.	*Total Hydro*	0.00	4.73	13.43	5.02	4.59	3.14
	Total Renewable Energy	**329.66**	**333.38**	**357.78**	**328.64**	**254.09**	**282.85**
10.	**Total Nuclear Fission**	**1104.87**	**1035.79**	**895.08**	**800.81**	**755.65**	**780.80**
11.	**Total Nuclear Fusion**	**421.39**	**398.44**	**389.41**	**367.62**	**332.09**	**301.89**
	Fission/fusion	**1526.26**	**1434.23**	**1284.49**	**1168.43**	**1087.74**	**1082.69**
12.1	Electric Power Conversion	40.53	63.87	54.40	53.54	68.88	58.13
12.2	Electricity Transm. & Distr.	7.84	5.53	9.28	9.24	12.77	10.88
12.3	Energy Storage	15.13	12.42	11.54	9.95	13.03	9.28
12.	**Total Power & Storage Tech.**	**63.50**	**81.82**	**75.21**	**72.73**	**94.68**	**78.29**
13.1	Energy Systems Analysis	30.81	30.67	43.03	21.85	18.55	19.98
13.2	Other Tech. or Research	341.57	351.31	124.25	136.44	127.91	116.91
13.	**Total Other Tech./Research**	**372.38**	**381.98**	**167.28**	**158.29**	**146.46**	**136.89**
	TOTAL ENERGY R&D	**2859.21**	**2730.22**	**2329.71**	**2138.93**	**1923.38**	**1893.49**
	Non-nuclear En. R&D	**1332.95**	**1295.99**	**1045.22**	**970.50**	**835.64**	**810.80**

Note: Computations on IEA data. Figures reported here do not include the expenditures made by Belgium, Finland, Greece and Ireland.

Table 4.: Government Energy R&D Budgets in EU Countries - MECU 1995

		1990	**1991**	**1992**	**1993**	**1994**	**1995**
1.1	Industry	86.01	96.89	78.81	92.10	67.40	58.65
1.2	Residential, Commercial	50.82	65.91	48.35	42.94	38.91	33.13
1.3	Transportation	44.89	36.46	42.27	45.94	39.94	34.26
1.4	Other Conservation	59.13	46.55	35.31	39.70	22.48	18.91
1.	**Total Conservation**	**240.84**	**245.80**	**204.75**	**220.67**	**168.73**	**144.96**
2.1	Enhanced Oil and Gas	20.57	11.89	16.50	28.27	32.03	26.45
2.2	Refining, Transport & Stor.	4.59	2.51	3.12	1.38	2.44	2.65
2.3	Oil Shales and Tar Sands	0.00	0.00	0.00	0.00	0.02	0.00
2.4	Other Oil & Gas	57.05	47.75	49.45	40.67	41.21	36.29
2.	**Total Oil & Gas**	**82.21**	**62.14**	**69.07**	**70.32**	**75.70**	**65.39**
3.1	Coal Prod., Prep. and Transp.	24.11	18.96	10.75	9.22	1.90	1.86
3.2	Coal Combustion	61.50	41.15	35.79	37.04	27.26	18.36
3.3	Coal Conversion	16.95	16.70	12.94	7.22	5.24	3.19
3.4	Other Coal	19.96	17.77	9.47	6.37	7.58	5.36
3.	**Total Coal**	**122.53**	**94.58**	**68.95**	**59.85**	**41.99**	**28.77**
	Total Fossil Fuels	**204.74**	**156.72**	**138.02**	**130.17**	**117.69**	**94.16**
4.1	Solar Heating & Cooling	33.66	36.44	34.09	37.75	28.86	22.95
4.2	Solar Photo-Electric	86.08	91.20	98.24	97.49	75.47	64.56
4.3	Solar Thermal-Electric	16.33	14.24	10.92	9.52	7.04	9.92
4.	*Total Solar*	*136.08*	*141.89*	*143.25*	*144.76*	*111.38*	*97.44*
5.	*Wind*	*66.31*	*60.86*	*56.61*	*67.42*	*46.09*	*70.13*
6.	*Ocean*	*5.49*	*6.03*	*1.69*	*2.36*	*1.35*	*0.66*
7.	*Biomass*	*35.48*	*42.39*	*56.51*	*53.36*	*45.59*	*42.50*
8.	*Geothermal*	*15.53*	*14.04*	*7.22*	*8.47*	*5.52*	*3.12*
9.1	Large Hydro (>10 MW)	*0.00*	*3.30*	*3.05*	*3.67*	*3.57*	*2.05*
9.2	Small Hydro (<10 MW)	*0.00*	*0.52*	*7.29*	*0.61*	*0.29*	*0.35*
9.	*Total Hydro*	*0.00*	*3.82*	*10.34*	*4.29*	*3.86*	*2.40*
	Total Renewable Energy	**258.88**	**269.03**	**275.62**	**280.65**	**213.79**	**216.25**
10.	**Total Nuclear Fission**	**867.65**	**835.85**	**689.53**	**683.87**	**635.80**	**596.94**
11.	**Total Nuclear Fusion**	**330.92**	**321.53**	**299.98**	**313.94**	**279.42**	**230.80**
	Fission/fusion	**1198.57**	**1157.38**	**989.52**	**997.81**	**915.22**	**827.74**
12.1	Electric Power Conversion	31.83	51.54	41.91	45.72	57.96	44.44
12.2	Electricity Transm. & Distr.	6.16	4.46	7.15	7.89	10.74	8.32
12.3	Energy Storage	11.88	10.02	8.89	8.50	10.96	7.09
12.	**Total Power & Storage Tech.**	**49.87**	**66.03**	**57.94**	**62.11**	**79.66**	**59.85**
13.1	Energy Systems Analysis	24.20	24.75	33.15	18.66	15.61	15.28
13.2	Other Tech. or Research	268.23	283.50	95.72	116.52	107.62	89.38
13.	**Tot. Other Tech./Research**	**292.43**	**308.25**	**128.87**	**135.18**	**123.23**	**104.66**
	TOTAL ENERGY R&D	**2245.34**	**2203.21**	**1794.71**	**1826.58**	**1618.33**	**1447.62**
	Non-nuclear En. R&D	**1046.76**	**1045.83**	**805.19**	**828.78**	**703.10**	**619.88**

Note: Computations on IEA data. Figures reported here do not include the expenditures made by Belgium, Finland, Greece and Ireland.

Table 5.: R&D expenditure shares in the EU countries

R&D Expenditure shares	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
% Nuclear Fission	43,89	43,54	40,58	39,99	42,09	43,95
% Nuclear Fusion	16,74	16,75	17,66	18,36	18,50	16,99
% Non-nuclear	39,38	39,71	41,76	41,65	39,42	39,06

Table 6.: Government Energy R&D Budgets in EU Countries: ***Million US$ - 1995 prices***

		1990	**1991**	**1992**	**1993**	**1994**	**1995**
13.1	**Energy Systems Analysis**	**30.81**	**30.67**	**43.03**	**21.85**	**18.55**	**19.98**
1.1	Industry	109.52	120.06	102.31	107.85	80.10	76.72
	RUE in Buildings	107.57	126.83	107.02	94.48	80.55	73.36
1.3	Transportation	57.16	45.18	54.87	53.79	47.47	44.81
1.4	Other Conservation	75.30	57.69	45.84	46.49	26.72	24.74
12.	Total Power & Storage Tech.	63.50	81.82	75.21	72.73	94.68	78.29
	Total RUE	**413.05**	**431.58**	**385.25**	**375.34**	**329.52**	**297.92**
4.	*Total Solar*	130.42	130.67	141.69	125.31	98.07	97.43
5.	*Wind*	84.44	75.42	73.48	78.95	54.78	91.73
6.	*Ocean*	6.99	7.47	2.19	2.76	1.61	0.86
7.	*Biomass*	45.18	52.53	73.36	62.48	54.18	55.59
8.	*Geothermal*	19.77	17.40	9.37	9.92	6.56	4.08
9.	*Total Hydro*	0.00	4.73	13.43	5.02	4.59	3.14
	Total Renewable Energy	**286.80**	**288.22**	**313.52**	**284.44**	**219.79**	**252.83**
2.	Total Oil & Gas	104.69	77.01	89.66	82.34	89.97	85.53
3.	Total Coal	156.03	117.20	89.50	70.09	49.90	37.63
	Total Fossil Fuels	**260.72**	**194.21**	**179.16**	**152.43**	**139.87**	**123.16**
	Total R&D	**991.38**	**944.68**	**920.97**	**834.06**	**707.73**	**693.89**
13.2	**Other Tech. or Research**	**341.57**	**351.31**	**124.25**	**136.44**	**127.91**	**116.91**
	Total Non-nuclear energy	**1332.95**	**1295.99**	**1045.22**	**970.50**	**835.64**	**810.80**

Note: Computations on IEA data. Figures reported here do not include the expenditures made by Belgium, Finland, Greece and Ireland.

Table 7.: Government Energy R&D Budgets in EU Countries: ***MECU - 1995***

		1990	1991	1992	1993	1994	1995
13.1	**Energy Systems Analysis**	**24.20**	**24.75**	**33.15**	**18.66**	**15.61**	**15.28**
1.1	Industry	86.01	96.89	78.81	92.10	67.40	58.65
	RUE in Buildings	84.47	102.35	82.44	80.68	67.77	56.09
1.3	Transportation	44.89	36.46	42.27	45.94	39.94	34.26
1.4	Other Conservation	59.13	46.55	35.31	39.70	22.48	18.91
12.	Total Power & Storage Tech.	49.87	66.03	57.94	62.11	79.66	59.85
	Total RUE	**324.37**	**348.27**	**296.78**	**320.53**	**277.26**	**227.77**
4.	*Total Solar*	*102.42*	*105.45*	*109.15*	*107.01*	*82.52*	*74.49*
5.	*Wind*	*66.31*	*60.86*	*56.61*	*67.42*	*46.09*	*70.13*
6.	*Ocean*	*5.49*	*6.03*	*1.69*	*2.36*	*1.35*	*0.66*
7.	*Biomass*	*35.48*	*42.39*	*56.51*	*53.36*	*45.59*	*42.50*
8.	*Geothermal*	*15.53*	*14.04*	*7.22*	*8.47*	*5.52*	*3.12*
9.	*Total Hydro*	*0.00*	*3.82*	*10.34*	*4.29*	*3.86*	*2.40*
	Total Renewable Energy	**225.22**	**232.59**	**241.52**	**242.90**	**184.93**	**193.30**
2.	Total Oil & Gas	82.21	62.14	69.07	70.32	75.70	65.39
3.	Total Coal	122.53	94.58	68.95	59.85	41.99	28.77
	Total Fossil Fuels	**204.74**	**156.72**	**138.02**	**130.17**	**117.69**	**94.16**
	Total R&D	**778.53**	**762.33**	**709.47**	**712.26**	**595.48**	**530.50**
13.2	**Other Tech. or Research**	**268.23**	**283.50**	**95.72**	**116.52**	**107.62**	**89.38**
	Total Non-nuclear energy	**1046.76**	**1045.83**	**805.19**	**828.78**	**703.10**	**619.88**

Note: Computations on IEA data. Figures reported here do not include the expenditures made by Belgium, Finland, Greece and Ireland.

Table 8.: Technology shares in EU government energy R&D expenditures

		1990	1991	1992	1993	1994	1995
13.1	**Energy Systems Analysis**	**3.11**	**3.25**	**4.67**	**2.62**	**2.62**	**2.88**
1.1	Industry	26.51	27.82	26.56	28.73	24.31	25.75
	RUE in Buildings	26.04	29.39	27.78	25.17	24.44	24.62
1.3	Transportation	13.84	10.47	14.24	14.33	14.41	15.04
1.4	Other Conservation	18.23	13.37	11.90	12.39	8.11	8.30
12.	Total Power & Storage Tech.	15.37	18.96	19.52	19.38	28.73	26.28
	Total RUE	**41.66**	**45.69**	**41.83**	**45.00**	**46.56**	**42.93**
4.	*Total Solar*	*45.47*	*45.34*	*45.19*	*44.05*	*44.62*	*38.54*
5.	*Wind*	*29.44*	*26.17*	*23.44*	*27.76*	*24.92*	*36.28*
6.	*Ocean*	*2.44*	*2.59*	*0.70*	*0.97*	*0.73*	*0.34*
7.	*Biomass*	*15.75*	*18.23*	*23.40*	*21.97*	*24.65*	*21.99*
8.	*Geothermal*	*6.89*	*6.04*	*2.99*	*3.49*	*2.98*	*1.61*
9.	*Total Hydro*	*0.00*	*1.64*	*4.28*	*1.76*	*2.09*	*1.24*
	Total Renewable Energy	**28.93**	**30.51**	**34.04**	**34.10**	**31.06**	**36.44**
2.	Total Oil & Gas	40.15	39.65	50.04	54.02	64.32	69.45
3.	Total Coal	59.85	60.35	49.96	45.98	35.68	30.55
	Total Fossil Fuels	**26.30**	**20.56**	**19.45**	**18.28**	**19.76**	**17.75**
	Total R&D	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
13.2	**Other Tech. or Research**	25.63	27.11	11.89	14.06	15.31	14.42
	Total Non-nuclear energy	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Note: Computations on IEA data. Figures reported here do not include the expenditures made by Belgium, Finland, Greece and Ireland.

3. RESULTS OF THE SENSER SURVEY: EMERGING TRENDS IN GOVERNMENT AND PRIVATE RTD EXPENDITURES IN 1994-96

3.1 AGGREGATE DATA

Data on non-nuclear (N-N) energy **government RTD budgets** at the national levels and in national currencies are reported for years 1994, 1995, 1996 in Table A.1.1 of the Appendix. With respect to the classification adopted, data are indicated with a level of aggregation corresponding to a two-digit level.

Figures reported in the tables concern Austria, Belgium, Denmark, Finland, Germany, Greece, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom. As data supplied for Ireland refer to 1992, no comparison is possible with the data for the other countries. Thus for this country only considerations on budget shares for the various technological areas will be made.

In general, government R&D budgets seem to be stationary or slightly decreasing, with few exceptions (e.g. Greece). However, data are not available for all three years considered (1994, 1995, 1996) in all countries: in particular they are not available for 1996 for Austria, Belgium (Wallonia), the Netherlands, Sweden. Also, 1996 figures are sometimes provisional. Furthermore, as mentioned, no data are available for Ireland for the period considered (1992 data, although very detailed, were supplied instead).

Total government budgets for non-nuclear RD&D in the EU countries show a decrease from 612.9 million in 1994 to 587.7 million ECUs in 1995 (Table A.1.2). If the expenditures for dissemination activities are included, the totals in the two years rise to 717.2 million and 702.6 million ECU respectively. Total RD&D expenditures (including dissemination) for 1996 are not comparable due to missing or incomplete data for four countries, but they amounted to 595.1 million ECU.

Trends may be different at the individual country level. As shown in Table A.1.2, from 1994 to 1995 government budgets grow only slightly in some countries (Austria, Belgium, France, Norway), show a more definite increase in others (Denmark, Finland, Greece, Italy, the Netherlands) but the total decrease in the latter group (which includes Germany, Portugal, Sweden and the United Kingdom) more than offsets the gain in the former group.

If the period 1995-96 is considered, government budgets increase in Germany, Greece, Italy, Spain and decrease in Denmark, Finland, France, Norway, Portugal and the United Kingdom.

If R&D and demonstration activities are considered only, we can see (Table A.1.3) that, on average, in 1994-95 activities on **energy RTD strategies** represent about 2.8% of government budgets, while activities on **RUE** represent 41.8%, **renewables represent** 34.7% and **fossil fuels** represent about 20.6%.

Within these four broad categories, the weights of the various components differ. Activities on RUE are almost evenly distributed between the building sector, the industrial sector and the energy industry (25-30% each), while the transport sector gets a smaller share of the budget (about 14%).

Activities on renewables concentrate mostly on solar photovoltaic (32%), wind (21.6%) and biomass (22.1%). Budgets for hydro- and geothermal energy are progressively decreasing while advanced energy storage and cross-cutting technologies budgets are slightly increasing.

Concerning RTD on fossil fuels, 61% of the budget is concentrated on liquid and gaseous hydrocarbons and another 23% goes to clean technologies for solid fuels and gas.

Data collected on **private RTD expenditures** have strong limitations both because only nine countries out of 15 gave any information on this subject, and because that information does not seem to be complete (not all major private energy companies were covered, coverage may be in full for one year and partial or nil for the next, etc.). The countries that supplied information on private budgets were Austria, Belgium, France, Greece, Italy, Norway, Portugal, Spain and the United Kingdom, but two of them were unable to give data for 1996. Thus, unfortunately, such countries as Germany, Sweden and the Netherlands, which represent a substantial share of total R&D expenditures by the private sector in Europe, did not supply even partial information.

As shown in Table A.2.2, private RTD budgets outweigh government budgets (673.6 million ECU in 1994, 731.9 million ECU in 1995, 593.1 million ECU in 1996), especially considering that these figures concern only nine countries. The main areas of interest in private budgets seem complementary with respect to government budgets.

As shown in Table A.2.3, technologies related to fossil fuels represent the largest and still growing share of energy RTD funded by private companies (about 44.4%): 85% to 90% of this portion goes to hydrocarbons (oil and gas exploration, extraction, refining and transport) while clean technologies for solid fuels and gas represent from 6.9% to 3.5%.

Another large share of private funds is devoted to RUE (about 40%), but within this group, RUE in the energy industry represents the dominant portion: over 77% in the three years considered. RUE in transport attracts a slightly decreasing share (9.8% to 8.4%), while RUE in industry remains at around 6-7%.

Renewables represent a decreasing share of private RTD budgets (from 13.6% in 1994 to 12.5% in 1996). In this area the favourite options seem to be wind power (increasing its share from 34% to 36%), solar photovoltaic (decreasing from 27% to 22%), hydropower (increasing from 15% to 18%) and biomass (increasing from 13% to 19%).

Finally, RTD strategies represent less than 0.5% of the total budget in the period considered.

The role of the private sector in mature, commercial technologies is thus confirmed: their activity is particularly important in the oil and gas industry and in the electric industry. In both cases, as shown by the qualitative analysis on research activities, the efforts seem to be concentrated on incremental improvements of the performance of plants/processes and products in terms of costs, reduced emissions or efficiency gains.

A detailed analysis, country by country, could be carried out, but the poor quality and the incompleteness of the data would advise against putting much confidence in them: the sum of private expenditures reported for Italy and the UK represented about 85% and 70% of the total for the nine countries considered in 1994 and 1995, and 89% of the total for the seven countries considered in 1996.

3.2 COUNTRY DATA

As a general consideration on the results of this quantitative analysis, it can be said that wide differences exist concerning the areas of greater interest at the national level: these depend on climatic conditions, resource endowment, industrial base, and comparative advantage in the international economic system. Budgets tend to focus more on the really promising areas.

Let us briefly examine, on a country by country basis, the RTD priorities as expressed by the average relative shares of the various technologies in the national budgets, in the years 1994-95.

Austria

The total **public budget** spent by Austria on energy RD&D in 1994-95 represents about 3.6% of the total non-nuclear energy public budget of the 14 EU countries considered.

The greatest budgetary effort in this county is spent on rational use of energy (around 65.5% of the Austrian government budget for energy RTD and about 5.7% of the total EU-14 budget for RUE in 1994-95).

Within this group the largest shares are for RUE and new fuels in the transport sector (from 27% to 32% of total expenses on RUE, a higher share than the EU countries average), and for the energy industry (from 28% to 26%). The share devoted to RUE in buildings seems to be growing (20%-30%) while the share of RUE in industry falls (from 24% to 12%).

The budget for renewables is growing and represents from 27% to 31% of total government energy RTD: this is a lower share than the EU-14 average, as indicated by a “specialisation index” of 72.5.

However, a higher than average and increasing share (from 60% to 68%) of the total budget for renewables is directed towards activities on energy from biomass and waste, while the share of solar photovoltaics is lower than average and decreasing (from 25% to 15%). The budget share for hydroelectric power is also higher than average and increasing.

Activities on fossil fuels maintain more or less the same share of the total budget (from 3.9% to 3.8%) but the attention seems to be concentrated on solid fuels extraction, preparation and transport.

Of the total **private energy RTD** budgets reported for Austria, 70% concentrated on rational use of energy, with RUE in transport taking the largest share (from 34.5% in 1994 to 53.8% in 1995). The share of funds attracted by RUE in buildings increased from 12% to 26% while RUE in industry and in the energy industry lost share.

Renewables absorbed the remaining share of private expenditures (from 20.8% in 1994 to 29% in 1995) but nearly 80% of it went to energy from biomass and waste.

Research on fossil fuels remained around 1.2% to 1.7%.

Therefore, priorities expressed by private R&D expenditures in Austria are rather consistent with those expressed by government budgets.

Belgium

The total **public budget** spent by Belgium on energy RD&D in 1994-95 represented 2.4% of the total N-NE public budget of the EU-14.

Around 71% of the public RTD budget in Belgium was spent on technologies for rational use of energy in those two years. The RUE share of the Belgian budget was higher than the average RUE budget share in the total EU-14 countries.

Within this area, the shares of the various sectors of activity kept changing, although there seemed to be a predominance of activities for RUE in the transport sector (a share 2-4 times the average EU-14 share).

Renewables obtained an increasing share of the budget (from 13.7% in 1994 to 18.4% in 1995) but their overall share is much lower than the EU average. Data on the breakdown of these funds are incomplete and it is impossible to identify trends in RTD priorities, but about 40% of the expenditures on renewables were devoted to activities on biomass and waste and another 36-38% to solar photovoltaics.

A decreasing – and lower than average – proportion of the budget (from 13.2% in 1994 to 10.8% in 1995 and to 5.6% in 1996) went to RTD on fossil fuels.

Like Austria, about 95% of **private energy RTD budgets** reported for Belgium concentrated on research for rational use of energy, more or less evenly distributed between RUE in buildings and RUE in industry. The remaining 5% went to research on fossil fuels (in fact to hydrocarbons research).

Denmark

The **total public budget** spent by Denmark on energy RD&D in 1994-95 represented 3-4% of the total N-NE public budget of the EU-14. The allocation of this budget is focused on a well defined set of priority technologies or technological areas

Compared to other countries, a fairly large share of the Danish RTD budget on energy is spent on energy RTD strategies (5%). The share assigned to rational use of energy is higher than average but in 1994-95 it has decreased from 54% to 51% of total energy RTD. Within this group, the energy industry (with fuel cells and storage) obtains 47% to 44% while the building sector gets 38% to 45%: in both cases the expenditure share is higher than the EU average. RUE in industry gets the rest, while no government research seems to be done for RUE in the transport sector.

The share of renewables goes from 25% to 31% of total government RTD on energy (a share lower than the EU average), but the effort is entirely concentrated on wind and biomass. However, while in 1994 wind energy has a share of 70% and biomass gets 30% of the budget for renewables, in 1995 the situation is reversed and wind energy gets 40% while biomass increases to 60%.

RTD on fossil fuels represents about 15% of the total government budget: a smaller share than the EU average. All of it is concentrated on hydrocarbons.

Finland

The **total public budget** spent by Finland on energy RD&D in 1994-95 represented a growing share (from 7.5% to 9.3%) of the total N-NE public budget of the EU-14.

The growing government budget for energy RTD in Finland is concentrated for about 50% (49.7% in 1994 and 56.9% in 1995) on rational use of energy: this share is higher than the EU average. More than 35% of the budget on RUE is assigned to activities for the industry (mostly targeted towards energy efficiency improvements in the metallurgical and pulp and paper industries) and another 34% goes to the energy industry (including fuel cells and storage). The share of RUE in buildings has decreased from 22% to 15%; the share of RUE in transport has dropped from 6% to less than 3% and is now lower than the average for the EU.

Renewables represent a lower than average and decreasing share of the total budget (from 16.8% to 14.7%). Furthermore, most of the RTD on renewables (over 60%) concentrates on energy from biomass and waste, while the rest is increasingly being spent on further options (about 30%) and wind energy (1.6% to 4.1%): solar photovoltaics seem to be progressively abandoned (from 6% to less than 5%). The share of R&D budgets for biomass is much higher than the EU average. Other areas of activity among renewables get funding in negligible amounts.

RTD on fossil fuels represents a decreasing share of the total budget (from 13% in 1994 to 11.7% in 1995) and the focus of research in this area seems to be on combustion technologies (more than 90% in 1994-95). Oil and gas and other hydrocarbons account for the rest.

France

The **total public budget** spent by France on energy RD&D in 1994 represented 9.3% of the total N-NE public budget of the EU-14.

The energy RTD budget in France showed a strong focus towards fossil fuels. This technology area attracted about 60% of total government funding (60% in 1994 and 59% in 1995), i.e. about three times the EU average share. Within this area, hydrocarbons represented a share of about 85% in 1994-95, while clean technologies for solid fuels and gas represented 13% in the same years. Solid fuels extraction, preparation and transport obtained the remaining 1-2%.

Rational use of energy represented in both years 29% of the total public budget on energy RTD, that is, a lower share than the EU average. Of the total budget on RUE, research in the industry sector obtained 47% in 1994 and 57% in 1995. RUE in buildings was 23-24% in 1994 and 1995. RUE in the transport sector (including new fuels) represented 33% in 1994 and dropped to less than 20% in 1995. Finally, renewable energy sources attracted 10-11% of the total public resources for energy RTD in both years: much less than the EU average. The bulk of it went to research on solar photovoltaics (decreasing from 39.5% in 1994 to 20% in 1995), biomass (increasing from 32% in 1994 to 53% in 1995), and geothermal energy (20% in both years). A slim 5% was left for wind power. No estimate on government funding of research on energy RTD strategy was supplied.

Concerning **private energy RTD budgets** reported for France, the figures represent 2-3% of total private budgets indicated for EU member countries, which puts a heavy question mark on the completeness of the data collected. The breakdown of these funds shows that research on rational use of energy absorbed 56.5% in 1994 and 61% in 1995: this is a much higher share than the one seen in public R&D. Of this total over 54% went to RUE and new fuels in transport, while the rest was split between RUE in buildings and RUE in industry.

A decreasing share (43.5% in 1994 and 39% in 1995) went to renewables. In this group geothermal energy attracted 35-40% of the resources, followed by solar photovoltaics (from 27% to 35%), biomass (16% to 20%) and wind power (10% to 13%).

No information was made available concerning expenditures on fossil fuels.

Germany

The total public budget spent by Germany on energy RD&D in 1994 represented over 20% of the total N-NE public budget of the EU-14: as the figures available do not include the funds made available by the Laender, this very likely underestimates the real size of the German public R&D programmes.

In Germany the main share of Government budgets for energy RTD goes to renewables (56-57% in 1994 and 1995 and growing to an estimated 62% in 1996). It is worth noting that German RTD expenditures on renewables represent over 30% of the total EU budgets on the same technological area. Within this group of technologies, solar photovoltaics obtained 48-49% in 1994 and 1995 and nearly 51% in 1996; wind energy represented 28% in 1994, 32% in 1995 and 27% in 1996; in both cases the national share was higher than the EU average and expenditures represented about half the total public budgets in the EU Member Countries for solar PV and wind. Energy from biomass dropped from less than 4% in 1994 to zero afterwards; similarly, funding for hydropower research fell from less than 0.3% to zero; research on geothermal energy obtained 4% in 1994, 3% in 1995 and 1996. Advanced energy storage got 7.6% of the budget for renewables in 1994, 6.4% in 1995 and 8% in 1996 but this represents the entire government budget for this technology in the EU countries. The share of cross-cutting technologies grew from 7% in 1994 to 10.5% in 1995 and 11% in 1996 (again a substantial portion of the total EU government funding for these technologies).

The share of rational use of energy was 30% in 1994, 33% in 1995 and 25% in 1996: a lower share than the EU average. However, the greatest effort in this area was spent on RUE in buildings: 42% in 1994, 52% in 1995 and 48% in 1996, representing over one-fourth of the total EU government funding for these technologies. RUE in the energy industry (including fuel cells and storage) obtained 39% in 1994, 32% in 1995 and 33.5% in 1996. RUE in industry received 15-18% in 1994-96. According to the data supplied, no federal funding was given to RUE and new fuels and transport, although it is known from other sources that a certain amount of the R&D expenditures made by the Ministry of Transportation is energy-related.

Fossil fuels obtained 14% of total government budgets in 1994, 10.4% in 1995 and again 13% in 1996. Most of these resources (over 82%) were spent on clean technologies for solid fuels – of which Germany is an important producer – and gas. This share was higher than the EU average and represents over 40% of total funding of EU governments for these technologies. Solid fuels extraction preparation and transport got 2.4% of the fossil fuels budget in 1994, 3% in 1995 and no funds in 1996. On the other hand, hydrocarbons received 15% in 1994, 5% in 1995 and again 11.8% in 1996.

No estimate on government funding of research on energy RTD strategy was reported.

Greece

The total **public budget** spent by Greece on energy RD&D in 1994 represented about 0.5% of the total N-NE public budget of the EU-14, but this share grew to 0.9% in 1995 and 1.2% in 1996.

In this country, the largest share of government budgets for energy RTD went to renewables: 38.5% in 1994, 45% in 1995 and 40% in 1996. Of the total budget for renewables, wind, biomass and geothermal energy received the largest sums; their share of total funds were higher than EU averages. Wind energy received 37.6% in 1994, 26.3% in 1995 and 46% in 1996; biomass decreased from a share of 34.3% in 1994, to 28.9% in 1996; geothermal energy got 16% in 1994, 34.5% in 1995, 20.5% in 1996. The rest of the funding for renewables went to solar photovoltaics, hydropower and wave energy.

Fossil fuels maintained a fairly constant share of total energy RTD funding: 25.6% in 1994 and 27% in 1995 and 1996: a higher share than the corresponding EU average. Of this amount, the share that went to hydrocarbons was 60% in both 1994 and 1995, 62.7% in 1996.

Research on rational use of energy obtained decreasing shares: 32% in 1994, 16% in 1995 and 19% in 1996: lower values than EU averages. Within this technological area the share of RUE in buildings is the highest but has been falling from 77% in 1994 to 54.6% in 1996. On the other hand RUE in industry received increasing shares of funding: from 15% in 1994 to 42.4% in 1996. The share of rational use in transport remained below 10% in the three years considered while apparently no funding went to the energy industry.

Finally, Greece has been rapidly increasing the research funding effort on energy RTD strategy: from 4% of the total in 1994 to 12% in 1995 and 14% in 1996: much higher values than the corresponding EU averages.

Private energy RTD expenditures reported for Greece concentrated on rational use of energy in buildings (53.5% in 1994 and 36.1% in 1995) and on renewables (46.5% in 1994 and 64% in 1995). Research on renewables focused on wind energy (40% decreasing to 33%) and biomass (37% decreasing to 14%): an increasing share went to geothermal energy (10% to 35%) while solar PV kept a 9% share.

No expenditure was reported on fossil fuels.

Ireland

Data supplied for Ireland refer to the energy RTD budgets of 1992.

In that year **public expenditures** on rational use of energy represented about 56.5% of the total, while expenditures on renewables were 18.1% and funds for RTD on fossil fuels were 21.9%. Research on energy RTD strategies received the remaining 3.5% of the funds.

Within the budget for RUE, the highest share (57%) went to RUE in buildings (which includes renewable energy applications within buildings), 32% went to RUE in industry, 7% went to RUE in transport and the remaining 4% went to the energy industry.

Within the budget for renewables, 28% went to energy from biomass while the rest went to hydropower. Finally, the entire budget for R&D on fossil fuels went to hydrocarbons.

Italy

The total **public budget** spent by Italy on energy RD&D in 1994 represented about 13.6% of the total N-NE public budget of the EU-14.

Research on rational use of energy received 69% of total government funding for energy RTD in 1994, 62% in 1995 and 65% in 1996: i.e. much higher shares than corresponding EU averages. Of these funds, RUE in the energy industry, including fuel cells and storage, obtained 37.9% in 1994, 32.4% in 1995 and 35.4% in 1996; RUE in industry obtained a decreasing share (28.2% in 1994, to 24.3% in 1996); RUE in buildings received 21.7% in 1994, 20% in 1995 and 16.6% in 1996; RUE and new fuels in transport increased from 12.2% in 1994 to 23.6% in 1996. All these shares are higher than the corresponding values for the whole EU.

RTD on renewables was 30% of total government expenditures on energy research in 1994, 37% in 1995 and 34% in 1996: these values are lower than the corresponding average for the EU-14. These shares were in turn allocated as follows: solar photovoltaics received a decreasing share from 75.6% in 1994 to and 47.9% in 1996; energy from biomass and waste increased slightly from 21.3% in 1994 to 24.3% in 1996; wind energy got 3.1% in 1994, but grew to 23.5% in 1995 and 26.8% in 1996; finally, about 1% was spent in 1995 and 1996 on integration of renewable sources.

In the period considered no government funds were allocated for fossil fuels research.

Energy RTD strategy maintained a 1% share of total government budgets over the three years.

Private energy RTD budgets reported for Italy represented respectively 59.7% of the total for the EU-14 countries in 1994, 47% in 1995 and 63% in 1996.

In all three years 50% or more of the total expenditures went to rational use of energy, driven by RUE in the energy industry (86-88%) and about 7.5% by RUE in transport.

A little over 30% of the total private expenditures went to research on fossil fuels (basically hydrocarbons, for a share of 93% or more), while the remaining 14-16% went to renewables (42-45% to wind energy; 20-30% to solar PV and 20-25% to hydropower).

Netherlands

Data supplied for the Dutch **government budgets on N-N energy RTD** refer to the years 1994-95. In those two years these budgets represented about 7.5% to 8.4% of the total public budget of the EU-14.

In the same years 42% and 46% of the government budget went to research on rational use of energy, a decreasing share of 36% to 24% went to renewables, while the share of fossil fuels grew from 18% to 26% and 3-4% went to energy RTD strategy (a much higher share than the corresponding EU average).

Of the total budget for RUE, research for the building sector obtained 1% in 1994 and 26% in 1995, RUE in industry received 49.6% in 1994 and 30% the following year, RUE in the energy industry got 37-38% and RUE and new fuels in transport decreased from 11% to 7%.

The budget on renewables was allocated as follows: about 53% in both years to solar photovoltaics, 28% to 14% to wind energy and 18% to 33% to energy from biomass and waste. As can be seen solar PV in the Netherlands takes a higher share than its counterpart in the EU-14 aggregate expenditures. Finally, the budget allocation for fossil fuels went mostly to hydrocarbons – oil and gas – (54% in 1994 increasing to 85% in 1995), then to clean technologies for solid fuels and gas (31% in 1994 decreasing to 14% in 1995), and finally to generic combustion (14% in 1994 falling to zero in 1995).

No data were provided concerning **private sector** energy R&D budgets.

Norway

The total **public budget** spent by Norway on N-N energy RD&D in 1994-96 represented about 5-6% of the total public budget of the EU-14.

Over half (51% in 1994 and 54% in 1996) of total government funding of energy RTD in Norway went to fossil fuels, all of which to research on liquid and gaseous hydrocarbons: this share represents a much higher value than the EU-14 average.

Research on rational use of energy received 23-24% of total government funding in 1994-96, i.e. less than the average share of funds for this sector in the aggregate EU budgets. Of the overall budget for RUE, research on the energy industry (including fuel cells and storage) obtained 66% in 1994, 68% in 1995 and 64% in 1996; RUE in buildings obtained 19% in 1994 and 16% in 1995-96 while RUE in industry and RUE in transport split the rest (more or less 7-9% each in the three years).

Research on renewables obtained 23% of total government funds in 1994 declining to 20% in 1996. Following the natural resource endowment of this country, large shares of the funds on renewables went to hydropower and biomass: hydropower received 50% of the funding in 1994, 42% in 1995 and 64% in 1996 (10-20 times the EU average share); biomass received 25.4% in 1994 and 45% in 1995 and again 24% in 1996. Solar photovoltaics and wind energy received smaller but non-negligible shares: solar PV got 10% in 1994 and 6% in 1995-96; wind energy obtained 8% in 1994 and about 4% in 1995-96. Residual shares went to other options, geothermal energy and cross-cutting technologies.

Research on energy RTD strategies received 3% of total government budget in the three years, which is more than the share assigned to this type of research in the average EU-14 budgets.

Private energy RTD budgets reported for Norway in 1995 include also those of the oil and gas industry, not indicated for the previous year.

Expenditures on rational use of energy seemed fairly stable in absolute value. The largest – if decreasing – share in this group went to the energy industry (from 93.5% to 88%) but increasing attention is being given to the other areas.

Research on renewables focused entirely on biomass and waste (100%) in 1994, but in 1995 its share fell to 60% and rose again to 99% in 1996, with hydro and wind power research taking up the rest.

Portugal

The total **public budget** for N-N energy RD&D spent by Portugal in 1994 represented about 3.3% of the total public budget of the EU-14, but this share fell to less than 1% in 1995 and 1996.

According to the data obtained, the Portuguese government budget for energy RTD in 1994 appears strongly biased by a large investment in a geothermal power pilot plant: this investment represents over six times the budget for the remaining research activities in that year or in the following two years. Therefore, in order to give a more balanced view of the relative shares of the various research areas, the information is reported here in two versions: one for which the large geothermal project is included in the total budget and one for which that investment is excluded from the total budget of 1994.

In the first case, RTD on renewables represented 91.5% of the total budget in 1994, 52-53% in 1995 and 1996. Over 95% of that amount went to geothermal energy in 1994, but the share dropped to 3% or less in the following two years. Other options obtained a share of 2.6% in 1994 and increased to 43% in the following two years; solar photovoltaics grew from 1% in 1994 to 35% a year later and then fell to 16% in 1996; and biomass grew from less than 1% in 1994 to 31-32% in 1995-96. Research on RUE was about 4.6% in 1994, nearly 20% in 1995 and 10% in 1996, with 50-60% of the total devoted to RUE in industry and the rest to RUE in buildings (35.5% in 1994 decreasing to 18% in 1996) and to the energy industry (4% in 1994 increasing to 31% in 1996). Fossil fuels represented only 3.9% in 1994 but 22-24% in 1995-96: most of the budget concentrated on clean technologies for solid fuels (65.5% in 1994 but 100% in 1995-96) and on combustion technologies (34.5% in 1994).

If we do not take into account the large geothermal project, the resulting picture is the following. Over 50% of government RTD activities seems to concentrate on renewables (34.5% in 1994, 52% in 1995, 53% in 1996) and a large share of the expenses on renewables goes to solar photovoltaic (25-30%), biomass (30%), and tidal wave energy (>30-40%). RTD on fossil fuels attracts around 25% of total funds (but this share is decreasing), mostly devoted to clean coal technologies and combustion. A decreasing share of total funds (from 35% in 1994 to 10.6% in 1996) goes to rational use of energy.

Finally, relatively large and growing resources are being devoted to energy RTD strategies.

Private energy RTD budgets reported for Portugal indicate in 1995 and 1996 increasing expenditures on renewable energies, but these were almost entirely directed towards wave energy projects although smaller portions of total funds went to biomass, solar PV and to integration of renewable sources.

The small expenditure share that rational use of energy attracted showed irregular patterns: in 1994 100% went to RUE in the energy industry; in 1995 100% went to RUE in the transport sector and in 1996 57% was allotted to transport while the rest went to RUE in industry.

Spain

The total **public budget** spent by Spain on N-N Energy RD&D in 1994 represented about 7.7% of the total public budget of the EU-14. This share grew to 13% in 1996.

The public budget shows the following breakdown: a decreasing share (from 55% in 1994 to 34% in 1996) of the resources to research on renewables, an increasing share (from 29% in 1994 to 46% in 1996) to Rational use of energy, and a fairly constant share of 16-19% to fossil fuels.

The public funding on rational use of energy was allocated as follows: 40.7% in 1994 falling to zero in 1995 and returning to 13.6% in 1996 to RUE and new fuels in transport, 36.7% in 1994 decreasing to 20% in 1996 to RUE in buildings, 22.6% in 1994 increasing to 64% in 1996 to RUE in industry.

The total budget on renewables shows the following allocation: 12% in 1994, decreasing to 8.7% in 1996, go to solar photovoltaics, 18.8% in 1994, decreasing to 8.8% in 1996 to wind energy, another 16% in 1994, decreasing to 13.5 in 1996 to energy from biomass and waste, 17% in 1994 growing to 28% in 1996 to other options such as high temperature solar energy and finally 30% in 1994 increasing to 40% in 1996 to other cross-cutting technologies.

The budget on fossil fuels was spent on RTD for cross-cutting technologies (46% in 1994 increasing to 78% in 1996) solid fuels extraction, preparation and transport (8% decreasing to 4.5%), clean technologies for solid fuels and gas (15% decreasing to 9%) and combustion (29% decreasing to 7.8%).

Concerning **private budgets**, the largest share in the three years considered goes to fossil fuels (67-69%), 2-3% goes to rational use of energy, a decreasing share (from 11.6% to 3.4%) goes to renewables and a surprising 20-27% share goes to energy R&D strategy.

Sweden

The total **public budget** spent by Sweden on N-N energy RD&D in 1994 represented about 7.3% of the total public budget of the EU-14, decreasing in 1995 to 5.7%.

Government budgets for energy RTD have decreased from 1994 to 1995 but the breakdown among major areas has remained remarkably constant.

Research on rational use of energy obtained 63% of total funds in both 1994 and 1995: a higher share than the corresponding EU-12 averages. Of the global funding for RUE, the transport sector has received increasing shares: from 31% in 1994 to 41% in 1995; the energy industry fell from a 28.7% share in 1994 to 17.5% in 1995; the buildings sector received a share of 21.5% in 1994 and 25.3% in 1995; the industrial sector received 19% in 1994 and 16.5% in 1995.

Research on renewables maintained a 33% share of total government funding in both years, however the funding is mostly concentrated in two areas: biomass and wind. Of the total funds allocated to renewables, biomass obtained 61.6% in 1994 and 72% in 1995: these values are much higher than EU averages. Wind power received 23.5% in 1994 and 14% in 1995; solar PV and integration of renewable energies received 2.5% each in 1994 and 2.7% each in 1995; hydro- and geothermal energy received even smaller shares (data are incomplete).

Research funding for fossil fuels was 1.4% in 1994 and 1.9% in 1995. These funds were entirely devoted to two areas: cross-cutting technologies, which received 78.5% of this total in 1994 and 74% in 1995, and solid fuels extraction, preparation and transport, which received the remaining 21-26%.

Funding for research on RTD strategies has remained in both years at a level between 3% and 4% of total government expenditures on energy R&D.

United Kingdom.

The **total public budget** spent by the United Kingdom on energy RD&D in 1994 represented about 9% of the total public budget of the EU-14, but this share decreased to 7% in 1995 and increased again to 8% in 1996.

Government budgets for energy RTD in monetary value have decreased in the UK from 1994 to 1996. Furthermore, trends in the relative shares of the four major research areas indicate a move away from renewable sources and towards fossil fuels and RUE.

The largest share of the government budget goes to fossil fuels, which received 48% of the total in 1994, and 54% in 1995 and 1996: these proportions are more than double the EU average share. Expenditures for research on fossil fuels concentrated on hydrocarbons, clean technologies for solid fuels and on solid fuels extraction, preparation and transport. Hydrocarbons received a share of 62% in 1994, 57.5% in 1995 and 64% in 1996; clean coal technologies obtained 28.6% in 1994, 31.4% in 1995 and 28% in 1996; technologies for solid fuels extraction, preparation and transport obtained 3.4% in 1994, 2.6% in 1995 and 3.8% in 1996.

Renewables obtained 34% of total public funds in 1994, 27% in 1995 and 25.5% in 1996. Of the total budget for renewables, wind energy obtained 51% in 1994, 28.7% in 1995 and 36.5% in 1996; energy from biomass and waste received 23.7% in 1994, 37.7% in 1995 and 37.2% in 1996; integration of renewable sources received increasing funding shares: 10% in 1994, 20% in 1995 and 17% in 1996; geothermal energy, wave energy and hydropower obtained decreasing shares (from 6-7% to less than 3%) while solar PV increased its share from less than 1% to about 5%.

Research on rational use of energy grew as a share of total government RTD from 16% in 1994 to 17% in 1995 and 19% in 1996, but compared to EU-14 average this represents a much lower proportion. The total budget on RUE is apparently devoted to the buildings, industry and energy sector: no funds are indicated for the transport sector but some research relevant for energy purposes is funded by the Ministries of Environment and Transport. RUE in industry received 49.6% of the budget in 1994, 49.4% in 1995 and 41.3% in 1996: these are higher shares than corresponding EU averages for the same years. RUE in buildings obtained a share of 38.5% in 1994, 35.3% in 1995 and 42.3% in 1996; the energy industry, including fuel cells and energy storage received a share of 12% in 1994, 15.3% in 1995 and 16.3% in 1996.

Research on energy RTD strategy obtained decreasing shares of a shrinking government RTD budget: 2% in 1994 and 1% in 1995 and 1996.

Private energy RTD budgets reported for the United Kingdom went mostly (between 83% and 84%) to research on fossil fuels: 88% to 94% of it was on hydrocarbons and the rest to clean technologies for solid fuels and gas.

About 10-11% went to rational use of energy (and this was almost entirely devoted to the energy industry until 1995), while a 5.5-6.5% share went to renewables. Of the latter, about 40% was directed to research on biomass, 20-30% to solar PV and 27-30% to wind power.

3.3 CONCLUSIVE REMARKS ON RTD BUDGETS.

The results of this part of the research project seem to be consistent both with the results of other data sources (EUROSTAT, IEA) and with most elements that emerged from the analysis of market drivers.

The following remarks seem worth noting.

- EU governments funding of non-nuclear energy R&D in 1994-96, after a long period of dramatic cuts, may have reached a plateau. In real terms, funding is decreasing or at best stable.
- Government expenditures on non-nuclear energy represents about 75% of the public budget for nuclear energy (fission & fusion). In other words, EU government funding goes 60% to nuclear energy R&D and 40% to non-nuclear energy R&D.
- Government budgets for non-nuclear energy R&D are allocated as follows:
  - *energy RTD strategies* represent about 1.5%;
  - *RUE* represents 41-45%;
  - *renewables* represent 33-38%;
  - *fossil fuels* represent about 20%.
- The above breakdown is roughly confirmed by various information sources (EUROSTAT, IEA).
- Government funding is increasingly becoming the only source of financing for some technological areas that either have not reached a commercial stage (some renewable energy technologies), represent only niche markets, or are maintained as options for energy security purposes (some technologies for the use of low quality coals and peat, etc.).
- Concerning energy R&D budgets by the European Commission, the prevalence of funding for nuclear energy (fission + fusion + radioactive waste and decommissioning) is absolute: 81% in the period 1989-90 and 76% in the period 1993-94.
- More recently, EC funding for renewables and for rational use of energy seems to be increasing, while funding for R&D on fossil fuels technologies is falling. These data, however, need verification.
- The role of the private sector in mature, commercial technologies is confirmed: the research efforts seem to be concentrated on incremental improvements of the performance of plants/processes and products in terms of costs, reduced emissions or efficiency gains.
- The wave of privatisations in the energy industry is causing RTD budgets to fall in the privatising companies but data on private budgets are insufficient to determine whether this is a long-term or a temporary phenomenon. Private investment for R&D seems fairly strong and unrelenting in the oil and gas industry and in power generation, but the focus has shifted towards short-term research.
- Usually trends in public RTD budgets are not contradicted by trends in private RTD expenditures (when a technological area is being abandoned in the private industry for technical reasons, it is not pursued further in the public sector). Success or failure of RTD efforts in any given technological area seem to play a decisive role in orienting (i.e. increasing or stopping) further research and budget allocations.
- EU funding has a strong propulsive role in countries such as Spain, Portugal and Greece.

- Research done in collaboration with other IEA countries, within various Implementing Agreements is often mentioned.
- Areas where government-sponsored research and reported private investment does not match the officially stated priorities are in most sub-areas of RUE and especially in the transport sector where some low polluting technologies (electric and hybrid cars, fuel cell powered vehicles, new fuels) have not reached the commercial stage and need strong support, and where the system aspects of mobility, including social aspects, need increasing attention. This mismatch may be only apparent owing to the classification systems used by government and industries and by the limited information supplied by industry, hence this issue should be further investigated.

4. NATIONAL RTD ACTIVITIES: AREAS OF INTEREST

The following pages summarise the results of the qualitative information on national RTD activities on energy, by macro-areas (two-digit level of the classification adopted for energy RTD activities in the chapter 2 of the country reports). For each area, a short summary is provided on the main areas of research being pursued in the EU countries. More detailed information (at the four-digit level of our classification) on specific technologies is given in the appendix.

The value of total R&D expenditures, by national governments and, separately, by the private industry (based on the limited information available for nine countries) is also reported, together with additional comments and considerations.

Where possible, for each area of R&D carried out within the EU, an indication is given of the countries involved in that type of research, to help identify opportunities for co-operation among the various countries.

It is, however, important to stress the following:

- information reported hereafter has been extracted from the various country reports, although misinterpretation and some inaccuracies in our synthesis may have taken place;
- the level of detail in the information supplied by the various countries varies enormously but it is clear that detail on technological areas and sub-areas investigated decreases as the size of a country's research programme and budgets increases. Countries with the largest and most significant energy research programmes tend to be also the ones that supply the least information on R&D content. At the two ends of the range we have, for instance, Belgium or Greece and Germany. Hence we may have very rich and detailed information on small, sub-critical or marginal research activities and too little input on really large programmes with potentially significant impacts. As the Topic Leader could not take the place of the national teams in this task, correction of this bias is expected from a thorough review of this section by the national teams.

4.1 ENERGY RTD STRATEGY

Total expenditures on energy RTD strategies in 1994 totalled 26.5 million ECUs, of which 17.1 million from government budgets and 9.4 million from private sources. Countries with the largest government expenditures (>10% of the total) in this area are: the Netherlands, Sweden, Norway, Denmark, Finland, the UK and Italy, but interest is also growing in Greece and Portugal. Germany and France did not indicate expenditures in this area but their involvement in this type of activity is well known and documented.

The "specialisation indexes", however, show that Austria, Denmark, Finland, Greece, the Netherlands, Norway, Sweden, the UK and (for 1995) Portugal spend more in this area than their share over total RTD expenditures.

On energy RTD strategies, all countries seem to have developed at least some tools (if not the full range) that can be used to support the energy RTD prioritisation process. However, this is not to say that those tools are actually used for RTD prioritisation purposes in all countries considered: in fact this practice (which deserves some encouragement) seems to be more common in Northern Europe.

Methods range from feasibility studies (Belgium), market studies (the Netherlands), to life cycle analysis (Finland, the Netherlands, UK), up to system studies and energy-economy-environment modelling (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Norway, the Netherlands, Sweden, UK). Modelling tools, however, seem more and more frequently used for simulation of specific environmental policy measures, for impact assessment purposes. In some countries (UK, Belgium, Denmark, Ireland, etc.) there is growing attention to socio-economic and behavioural aspects of energy technologies, and particularly to a better understanding of the barriers to the diffusion of energy-saving technologies.

4.2 RATIONAL USE OF ENERGY (RUE)

Total expenditures on rational use of energy in 1994 were 522.1 million ECUs, of which 249.2 million from government sources and 272.9 million from private sources. In 1995 the total decreased to 509 million. Countries with the largest government expenditures (> 10% of the total) were Italy, Germany, Finland, Sweden. If the "specialisation indexes" are used, however, one notices that Austria, Belgium, Denmark, Finland, Italy and Sweden show indexes > 100.

Rational use of energy represents a very important research area both for government and private RTD. However these activities are increasingly directed towards a general improvement of efficiency of production processes, new process and product development, waste and pollution control/reduction rather than focus on energy saving per se. In other words, energy saving is a result of a trend to cost reduction and "rational use of resources", in which the environment starts being recognised as a resource with limited assimilation capacity. This is increasingly the case for research related to the industry and the transportation sector, but also for the energy industry and the building sector. Energy prices are definitely not a factor capable of pushing towards energy conservation in a meaningful way but the increasing amount of industrial and urban waste being produced and the worsening condition of urban air quality due to traffic pollution are becoming a powerful enough reason to reduce energy and materials use and to increase recycling. Furthermore, the need to increase the competitiveness of the industry at large, to increase exports and maintain sufficient levels of employment have become important considerations in directing RTD expenditures.

4.2.1 RUE and renewable energy in buildings

Research budgets on RUE and renewable energy in buildings totalled in 1994 74.3 million ECUs, of which 62.5 million came from public sources and 11.8 million from private funds. Overall expenditures increased to 84.4 million in 1995, mostly due to public budget increases. The largest expenditures in this area are made by Germany, Italy, Sweden, Finland, Spain.

In general there seem to be still a lot of interest in R&D of technologies for RUE in buildings: the potential for energy saving in this sector is important and the budgets (especially from governments) are still relevant. However, the very slow growth of population and the low turnover rate in buildings (especially in the residential sector) and in energy components/systems limit the market and the applicability of some of the most energy-efficient technologies. The largest market potential is in retrofitting and renovation and, as a consequence, there is a trend to concentrate R&D on cost effective retrofitting techniques. Also, there is a growing interest in product development and commercialisation for industrial purposes.

For the building envelope the most relevant areas of interest seem to be the following: insulation systems and materials (Austria, Belgium, Denmark, Finland, France, Italy); new heating systems (Finland); low-cost retrofit materials (France, Italy); technologies for new low-energy buildings (Germany, especially for new Landers).

For lighting, work is done on design of efficient devices (France), daylighting and evaluation of mixed natural-artificial lighting situations in test rooms (Italy, Germany).

Main research efforts on heating are in the following technologies: new efficient boilers (Austria, Italy) using solid fuel (Ireland) or natural gas (Italy, France). Heat pumps: single-stage absorption heat pumps operated by natural gas and working on the ammonia cycle and advanced multi-stage heat pumps (Italy); heat pumps and heat storage (Sweden). Heat storage technologies (Germany).

In cooling R&D concentrates on: passive and free cooling (Finland); demand-controlled ventilation (Finland, Austria, Belgium), electricity use and electrical installations (Finland); substitution of CFC and development of new thermodynamic cycle (adsorption) for cooling (Italy, France).

Research on heating and cooling with active and passive solar technologies focused on the following:

- Solar components: solar collectors (Austria); technology for hot water production (Greece), passive solar systems and components, solar supported heating and ventilation systems (Germany), building elements for natural cooling (UK);

- integration of solar technologies in buildings (Greece, Ireland). Solar-optimised buildings, solar near-district heating, community systems applications (Germany);
- valorisation of daylight inside the buildings (Belgium). Bioclimatic architecture of buildings (France, Italy). Passive ventilation (UK). Promoting uptake of passive solar design (UK);
- testing of buildings (Greece). Development of standards at a national, European and international level; solar systems certification (Greece).

Research activities on building management systems and control focus on: advanced control systems using informatics and telematics, including security, safety, remote metering, remote assistance (France, Germany, Denmark, Italy, Austria). Fault detection and diagnosis, open automation system architectures, energy management systems, control strategies, unit controls and control equipment (Finland). Computer software (Denmark). Components (Ireland). Demonstration activities in building management systems are carried out in all the countries mentioned.

Other R&D work is carried out on domestic appliances (France and Denmark) to increase insulation (refrigerators), reduce the needs for water (washing machines) and limit power consumption. Work on indoor air quality and ventilation is carried out in Italy.

Cross-cutting technologies studied concentrate on simulation techniques for design or retrofit (Belgium).

For storage research, activities concern underground storage and eutectics for short- or long-term storage (France); seasonal heat storage using water tanks (Italy). Electro-chemical storage (France). Electric heaters with heat storage (Italy).

4.2.2 RUE in industry

For this area of activity data on RTD expenditures are available mostly in aggregate form, and therefore the sum of sub-area figures does not match the total indicated by the country reports: this is particularly true for private industry data.

Total budgets spent on RTD for rational use of energy in industry amounted to 91.7 million ECU in 1994, of which 71.5 million was contributed by government sources and 20.20 million coming from private sources. In 1995 reported budgets seem to have increased to a total of 96.2 million, of which 78.1 million came from government sources and 18.1 million from private funds.

Countries that have indicated research activities in this area are Belgium, Denmark, Finland, France, Greece, Ireland, Italy, the Netherlands, Portugal, Sweden, and United Kingdom. Significant shares of the total public budget of EU countries for this technology area were spent in Finland, France, Germany, Italy (about 20%) and the Netherlands. However the specialisation indexes indicate that, relative to their share over the total EU-14 expenditures in this area, the highest efforts are made in Austria (in 1994), Belgium, Finland, France, Italy, the Netherlands and Sweden.

Concerning technologies for rational use of energy in industry, the country reports do not seem to satisfactorily cover the type of research being carried out in the various countries.

Public budgets in this area seem to be decreasing and the information is more complete concerning public than private R&D.

Little information is given about what is going on in energy-intensive sectors such as the chemical and petrochemical industry. More work is being done in the metallurgical industries (partly due to the general restructuring and downsizing of this industry, partly for CO_2 emission reduction purposes), in the pulp and paper industry and the construction materials industry (cement, ceramics, glass).

Activity also seems to be strong on recycling and pollution abatement and, for less energy-intensive industries, in a lot of cross-cutting technologies that are difficult to classify as specifically “energy saving” as well as in R&D for process and product innovation.

For **efficient use of energy in industry**, both public and private R&D efforts concentrate on cross-cutting technologies but, while in the private sector RTD on energy-efficient technologies is nearly always for energy-intensive industries, in the public budgets significant attention is devoted also to non-energy-intensive industries.

Research activities in energy-intensive industries mainly concern:

- improvement of energy efficiency in glass-melting furnaces, cement kilns and baking ovens through process modelling (Belgium). Performance modelling for ovens (United Kingdom). New energy-saving processes for the production of bricks and ceramic tableware (Italy). Drying of ceramic using microwaves (Belgium);
- management of energy consumption by using vacuum systems (Finland). Heat and power and process integration in the pulp and paper industry (Finland);
- drying, heat recovery, production of iron sponge, conversion systems using waste gas, pelleting, sintering and coking systems, melting processes and industrial furnaces, wind heating, scrap preheating, gas-plasm, use of waste gas (Germany). Pyrometallurgical production of copper and nickel based on the Outokumpu flash smelting process (Finland). Blast-furnace gas reheating in the metals and steel industry (Belgium). New processes for the production of intermetallic compounds, such as SHS (Self-propagating High-temperature Synthesis) (Italy). Ultra-short heat treatment for the reheating of steel, using high-frequency induction (Belgium). High-speed rolling and preforming and electric arc furnaces (Italy). Conduction and plasma for high temperature (Italy);
- flare gas recovery systems using variable speed compressor installed at refineries (Greece). Use of electrotechnology (induction for medium and high temperature, membranes for filtering, high-frequency drying) (Belgium).

Research interest in less energy-intensive industries concern mainly:

- energy-efficient, competitive air cycle heat pumps (also for cooling), air-conditioning and refrigeration systems (Ireland, Italy);
- microwave technologies and radio frequency for low-temperature heating (Italy). Drying processes (United Kingdom);
- membrane separation (United Kingdom, Italy);
- air blades for removal of liquids (Italy);
- more efficient electrical appliances, small electric motors, new washing and drying processes, variable-speed motors (Denmark, Italy, Ireland).

Research is developed around a large number of cross-cutting technologies: Heat exchange (France, Germany). Radiant energy, electro-magnetic radiant technologies applied to material transformation (France). Peltier effect (France). Use of electro-technology: induction for medium and high temperature, membranes for filtering (Germany, France). High-frequency drying (Belgium, France). Microwave technologies and radiofrequency for low temperature heating (Italy). Furnaces, contact-drying (Germany). Conduction (France, Italy). Plasmas (France, Italy, Germany). Catalytic processes, distillation/rectification processes (Germany). Crushing technologies (France). Compressors: pressurised air production (Germany). Mechanical compression of steam for medium-temperature heating (Italy). Pumps (Germany). Energy-efficient and competitive air cycle heat pumps (also for cooling) (France, Norway), air-conditioning and refrigeration systems (Norway). Climatisation technologies (Germany). Air blades for removal of liquids (Italy). Cogeneration (CHP), recovery of discharged heat (Italy). Rephasing (Italy). Plant automation (Italy). High-efficiency electric motors (especially variable-speed motors both for industrial processes) (France, Italy). More efficient small electric motors, new washing and drying processes (Denmark, Ireland). Bioprocesses (France). Interfaces to other sciences and technology fields such as microelectronics, micromechanics, lasers, sensors (Germany). Simulation technologies and systems analysis (Germany).

Concerning environmental pollution abatement, research activities on recycling were indicated by four countries: Belgium, Germany, Finland and Ireland, but Belgium reports activity in a large number of recycling fields including: use of residues (ash, cement, lime mixture) and cinders in the fabrication of building material (for road or buildings). Recycling of smoke from sinterisation, with the aim of a SO_2 emission reduction. Pyrolisor of fibre glass waste, for recycling in glass furnace. Energy valorisation in the cement industry of domestic waste and scrap residues from cars grinding. Recycling of glass products from electrical appliances or from cars. Recycling of textiles for the production of felt. Oil regeneration as an alternative to burning.

Germany also has relevant activities on recycling of industrial materials. Ireland works on sludge digestion, leachate treatment and industrial and municipal waste water treatment. Finland concentrates on recycled pulp production.

R&D on pollution abatement is indicated by Belgium, Denmark, Finland and Portugal.

Belgium reports a lot of activity, often carried out jointly between public and private research labs and with university involvement, in many areas including: research on improvement of combustion conditions, the installation of new de-polluting equipment for flue gases, the reuse of recuperated products in many industrial processes, the use of less polluting materials and processes.

Among activities carried out by the other three countries the following can be mentioned: flue gas cleaning from coal-fired power stations (Denmark, Portugal). Emission control in peat combustion and mixed fuel combustion; measurement and monitoring technologies; technologies for waste incineration (Finland).

4.2.3 Energy industry, fuel cells and storage

Reported total RTD expenditures on RUE in the energy industry, fuel cells and storage in 1994 was 288.8 million ECU, of which 77.0 million was contributed by government and 211.8 million by private industries. In 1995 the total amounted to 268 million, of which 71.8 million from government sources and 196.1 million from private sources. Significant shares of the total public budget of EU countries for this technology area are spent in Finland, Germany, Italy, and the Netherlands. But the specialisation indexes show that relatively important commitments are made in Austria, Belgium, Denmark, Finland, Italy, the Netherlands and Sweden.

Research focuses on electricity production, cogeneration, district heating, electricity transport and distribution (Belgium, the Netherlands, Norway, Sweden) and fuel cell technologies (Germany, Italy, the Netherlands, Sweden, United Kingdom).

R&D in the **energy industry** focuses on the following areas:

- electric power conversion (the Netherlands, Belgium, Portugal). Cogeneration and energy-efficient, low-emission power production systems (Spain);
- numerical control techniques of steam generators, heat exchangers, power stations, (Belgium, Ireland);
- steam injection gas turbine (Ireland). Testing of new turbines (Austria). Improvement in plant operation, upgrading, life extension and repowering of plants (Spain). Behaviour of structural materials (Spain). Steam power plants: steam generators, steam turbines and new materials (Germany);
- transport and storage of electricity (France);
- demand-side management and integrated resource planning (Austria, Portugal). Integration of new technologies in power systems (Portugal).

Research on **combustion processes** focuses on:

- cleaner combustion technology and new processes for flue gas cleaning in power stations (Denmark, Finland, Spain). Important research areas are : combustion processes (Germany); fluidised bed combustion (Finland), pressurised fluidised bed combustion and gasification (Finland), other gasification processes (Finland), coal gasification combined cycle (Germany, Netherlands); pressurised pebble-bed plants, pressurised coal-dust plants (Germany); high-temperature gas-cleaning (Germany); multicirculating fluid bed boilers (Denmark); black liquor recovery boilers and gasification (Finland), diesel power plants, waste incineration plants and conventional combustion (Finland);
- high-temperature turbine materials and components (Germany);
- combustion, burner and furnace modelling (Finland). Systems for monitoring and control of combustion to lower emissions. Modelling and simulation for pollution emission control (Greece);
- properties of fuels, emission formation chemistry, behaviour of ash (Finland).

R&D in **transmission, distribution and storage of electricity** concentrates on the following:

- work on batteries and transmission lines (Austria). Use of underground power lines. Polymer wires. Research on environmental problems related to high power lines (Belgium);
- transmission, distribution and storage (the Netherlands, United Kingdom);
- fault detection, load monitoring and prediction in the power grid (Finland, Spain). Integrated electricity distribution automation systems (Finland). Protection systems to prevent the spreading of malfunctions (Spain). Supply/voltage quality and reliability (transient stability and voltage security) (Belgium). Harmonics on line measurements. Research on communication protocols and hybrid data transfer systems. High-speed telecommunications in private networks. Continuous monitoring of hydro plants (Spain);

- frequency converter (Ireland). Flexible AC transmission systems (FACTS) for grid interconnections (Italy). "Custom Power" devices (power electronic converters and storage batteries) (Italy). Very high voltage DC transmission (Italy);
- research for the development of superconducting components. Cables with both low and high (with BICC) temperature materials (Italy);
- small batteries are being developed in Germany.

DSM: load control, peak clipping and energy conservation paralleled by supply-side management (technologies and programmes) (Finland). Expert system to forecast demand for electricity over a few days (Ireland). Disaggregated modelling of electricity consumption, including techniques for the integration of models on different timescales.

Research on **district heating and cooling** concentrates on:

- cogeneration and in particular small-scale CHP (Austria, Finland, Spain);
- district heating (Denmark, Finland, Germany, Italy);
- pre-insulated district heating pipes based on CFC-free insulation materials (Denmark).

Germany has an important programme in district heating and cooling, which considers both short- and long-term options. Among the applications of existing technologies for current district heating (DH) systems, the impacts of tensides, the possibility of restoring the existing DH system in East Germany, the planning and demonstration of new model concepts. Innovative heat-distribution systems and new methods for optimisation of plant operations are mid-term developments being studied, while among long-term options vacuum super insulation, mobile DH and optimisation of large systems are being considered.

Cross-cutting technologies being investigated include the following: behaviour of the structural materials (fatigue, corrosion, remaining life) used in power stations and their main components; continuous analysis for monitoring and equipment reliability (Spain); heat exchange, radiant energy, plasmas, cold plasmas, heat pumps, motors, Peltier effect, some electro-magnetic radiant technologies applied to material transformation, some advanced batteries, super condensers, use of supercritical water, components of the hydrogen chain (France).

In Belgium work is being done on multiphase systems; numerical simulations and measurements of water/vapour flows used to study the problem of security in a power station.

A fair amount of R&D is carried out in Europe on **fuel cells** and their applications, including the following.

- Phosphoric acid fuel cell - PAFC - (functioning at 80°C) of 200 kWe and an efficiency of 40-45% being tested for CHP applications; decentralised production of electricity; small portable or transportable units; and even electric or hybrid vehicles. The technology is currently at the demonstration stage (Italy, France): size 1.3 MWe has been reached.
- Molten carbonate fuel cells - MCFC - (Italy, the Netherlands, Sweden): duration of the electrodes and the cells, alternative cathode materials and doping of the electrolyte (Italy). Problems connected with scale-up (Italy). Improvement of MCFC stacks life and simplification of the fabrication process (Italy).
- Solid oxide fuel cells - SOFC - (Denmark, Germany, Italy, United Kingdom): development of internal gas reformers, catalysers able to work in extreme conditions for very long periods (40,000 hours or more) (Italy, United Kingdom). Small power plant (0.2 to 5 MW plants) applications are being studied in Germany. Corrosion-resistant materials for the electrodes and electrolyte (United Kingdom). A rectangular plan concept for a 1 kW SOFC module (Denmark). Design of stack (United Kingdom). Successful construction and testing a cell stack with a total of 70 (50 cm^2) cells with a maximum power of 507 W attained at an operation temperature of 1,000^{o}C (Denmark).
- Solid polymer electrolyte fuel cells - SPFC - (France, Italy, United Kingdom) for mobile applications with the target of a power density in the order of 0.25 kW/kg. Electrolytic membranes alternative to Naflon (Italy). Low Pt charging to reduce the immobilised cost of the catalyser (Italy). Corrosion-resistant materials for the electrodes and electrolyte, catalyst development and the design of fuel cell stacks (United Kingdom).
- Polymer electrolyte membrane fuel cells - PEMFCs - for transport (Germany). Demo vehicles (buses and cars), operated with PEMFCs fed by hydrogen (Italy). Hydrogen generation on board through the reforming

process, starting from methanol, optimisation of the volume/H_2 output ratio and the improvement of the reformer. Fuel-reformer aspects of fuel cells for vehicles fuelled with methanol (Italy).

4.2.4 RUE and new fuels in transport

Total RTD expenditures on RUE and new fuels in transport (mostly road) in 1994 amounted to 65.9 million ECU, of which 39.1 million was contributed by government and 26.8 million from private industries. In 1995 the total amounted to 56.5 million, of which 32.9 million from government sources and 23.5 from private sources. Total figures, however, do not correspond to the sum of the partial data by sub-area, which is much lower.

With respect to total budgets of EU governments in this technology area, significant shares are spent in Austria, Belgium, France, Italy, the Netherlands, Spain and particularly Sweden (over 22%). The same countries, except for the Netherlands, show a specialisation index above 100.

This area of research seems strategic for future quality of life in the EU countries but, looking at these data, does not seem to attract sufficient funding both from the government and the private sector. The data collected within this project on private sector spending would not indicate much interest by the industry in this area, but they are obviously incomplete and must be viewed with caution. We know from other sources that, for instance, the car industry in Germany spends substantial amounts of money on new vehicles. Of course it is possible (if unlikely) that large amounts of public money be spent on transport technologies, or on liquid biofuels. Furthermore, a lot of research money may be spent by the oil refining industry to improve the environmental performance of the conventional fuels. These hypotheses would be worth looking into.

Broad research areas being investigated are the improvement of transport logistics; improved information and communication technologies as well as guiding systems, alternative motor fuels and vehicles, electric and natural gas (hybrid) vehicles (Austria, Belgium, Finland, France, Germany, Italy, the Netherlands and Sweden).

Research activities on **decision support for energy management in transport** focus mostly on the following:

- technology assessment work on the impact of transport systems and technologies (Belgium, France, Finland);
- study of strategic aspects (mobility, spatial organisation of transports, transport economics) (France, Finland);
- research on transport and land-use planning, measures to reduce congestion, and the environmental impact of transport (United Kingdom). Models for the calculation of emissions from different technology and fuel alternatives; methods of valuation of the environmental and health impacts of emissions (Finland);
- modelling and analysis of transport systems especially in urban areas (Belgium, France, Italy);
- behavioural aspects and their mathematical representation at the regional, national and European levels (Belgium, Finland, Italy). Related transport management software for energy and logistic optimisation (Norway, Italy). Application of telematics to transport monitoring and management (Italy).

Research on **storage and conversion** concentrates on the following:

- fuel cells for transport applications: PAFCs (France, Italy); SPFCs (France, Italy, United Kingdom); PEMFCs (Germany, Italy);
- innovative batteries: lithium battery (Italy), advanced batteries and new electro-chemical couples (France). Super-capacitors (France);
- hydrogen production in reformers to supply fuel cells; hydrogen production by electrolytic processes; hydrogen storage (France, Italy).

RTD on **electrical vehicle systems integration and assessment** concentrates on: electric and hybrid vehicles (Belgium, France, Finland, Germany, Italy); charging, monitoring and managing batteries (France, Italy), charging networks (France).

Research on **new fuels** aim at improving combustion quality and efficiency:

- research on engines involving cars manufacturers and oil producers (France); improved engines, new catalytic exhausts and basic studies on the combustion with new fuels (Finland, Italy);

- research on fuels: properties of different fuels, fuel components and additives, petrol, petrol additives such as MTBE and ETBE or diesel fuel substitutes (France, Italy), diesel oil (conventional and reformulated) (Finland), gaseous fossil fuels (Belgium, Finland, United Kingdom), biomass-based fuels and biofuels, (alcohols, vegetable oils etc.) (France, Finland, Germany, Ireland, Italy, United Kingdom), synthetic fuels (Finland, France). Specific emissions with different deployment technologies (Finland). Use of hydrogen.

R&D activities on **technologies for clean and efficient vehicles** are carried out in the following areas:

- emission control with engine technology (diesel engine, turbo technology, intercooling, fuel injection, gas and alcohol or methanol driven vehicle engines) (Finland); gas-driven vehicles (Germany). Adaptation of energy-efficient technologies, emission control technologies and equipment to diesel engines (Finland). Fuel-efficient vehicles (Belgium, United Kingdom). Testing of engines with substitution fuels (colza, methanol, ethanol) and for pollution reduction (Belgium);
- advanced combustion technologies;
- development of electric and hybrid vehicles, ultra-low emission vehicles, sensor technology, materials technology (France, Germany, Italy). Fuel cells. Hybrids with thermal engine including those fuelled with natural gas (Italy). Viability of autonomous PV electric car, for urban use (Portugal). Ultra light steel car bodies (Belgium). Lightweight materials and manufacturing processes. Research on recycling of vehicles (life-cycle issues);
- high-power levitation/suspension and propulsion systems. Low-cost container ships (Ireland). New systems for rail and naval transport; new propulsion technologies, aircraft concepts and navigation tools for air transport. Aerodynamic freight vehicles (United Kingdom).

In the area of **technologies for management and control for more efficient and cleaner urban mass transit systems**, research activities concern mostly the following aspects.

Modelling of transport; development of a model and a numerical code for varying message panels (Belgium). Guided systems: high-speed train, urban transports, traffic management and safety (France). New technologies in freight transport (Belgium, France). ‘Smart roads’: data logging development and traffic engineering, onboard road information, toll systems, driving simulators, etc. (France). Traffic-system technologies for avoidance of traffic jams or shifting of transport tasks (Germany). Development of new simulation methods for public transport networks (Italy).

4.3 RENEWABLE ENERGIES (RE)

Total RTD expenditures on renewable energies in 1994 amounted to 316.1 million ECU, of which 224.2 million was contributed by government and 91.9 million by private industries. In 1995 the total was 271.2 million, of which 194.6 million from government sources and 76.6 from private sources.

As a general consideration, this broad research area is well covered in the country reports, probably due to the fact that the organisations participating in this study are also in charge of public RTD programmes and that research on renewables is mostly funded by national governments. All countries seem to carry out some research activity in one (or more) specific renewable resource area (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, United Kingdom). Specialisation patterns emerge clearly among countries. For instance, the budget of the German government alone represents over 30% of the total public budget allocated to renewables, but Greece, Portugal, and Spain spend significant shares of their national budgets in this area. Specialisation patterns are in part linked to local availability of the natural renewable resource, but often are the result of expertise and know-how developed at the national industry level. In some cases this expertise has become true technological leadership. Research budgets at the national level seem to streamline and concentrate on those technologies in which the country shows some favourable competitive position (if not actual leadership, at least reasonable expectation to be a significant player in the field).

4.3.1 System integration of different renewable energy sources

Reported total RTD expenditures on **system integration of different renewable energy sources** in 1994 amounted to 2.57 million ECU, of which 2.3 million was contributed by government and 0.26 million by private industries. In 1995 the total amounted to 3.3 million, of which 3.0 million from government sources and 0.3 from private sources. Over 75% of EU government budgets in this technology area were spent in the UK.

- Integration of renewable energies (solar, wind, biomass, hydro) is particularly oriented to develop solutions for energy and power supply in remote areas such as islands (Greece, Italy) or mountainous regions (Austria, Portugal, Italy).
- Hybrid supply systems consisting of wind, small hydro (pump-storage) are considered, including optimal operation and control of hybrid systems (Greece). Also integration of different renewables, diesel generators and battery storage (Italy); solar energy and biomass (demonstration) (Austria).

4.3.2 Solar photovoltaics

Total RTD expenditures on **solar photovoltaics** in 1994 amounted to 96.7 million ECU, of which 71.3 million was supplied by government and 24.9 million spent by private industries. In 1995 the total amounted to 78 million, of which 62.5 million from government sources and 15.5 from private sources. Concerning EU government budgets, 50% of the total expenditures on solar PV (or more) is appropriated by Germany alone, another 25% by Italy and more than 10% by the Netherlands: the rest is divided among the remaining countries.

The research on photovoltaics concerns materials, cells and modules.

- Techniques for fabrication of the materials (casting, thin layers) and for the commercial production of solar cells and photovoltaic modules (France, Germany, Italy, Finland, United Kingdom). On materials, activity in Italy is mainly focused on silicon (single- and multi-crystalline as well as amorphous). In France activity is focused on the multi-crystalline line which gives satisfactory results. GaAs studied only for space applications (Italy). Substantial research is being carried out in Germany aimed at cost reduction of PV modules at all scales.
- Regarding systems, some activity concerns passive sun-following (tracking) systems and low concentration, but most of the effort remains on fixed non-concentrating systems (Germany, Greece, Italy). Design and development of autonomous systems and PV systems for small grids; hybrid systems; BOS components (batteries, systems for power conditioning and control); PV systems monitoring; PVs in buildings (Germany, Greece, Italy, UK). Interconnection of small photovoltaics grids to the general electrical grid; power conditioning (Finland, Spain, United Kingdom).
- Much of the activity being carried out is in the demonstration phase. Applications being studied include air conditioning in industry and houses/buildings (Portugal), PV-houses, special PV-applications, self-sufficient energy units, solar heating, areal and district heating plants (Finland); integration of PV technology into various building types; PV technology use in southern climates for decentralised systems (Germany); utilisation for water treatment for human consumption (Portugal, Germany); pumping and water desalination (Greece). A large number of new applications for PV devices and small scale PV systems is being developed in Germany for various purposes (traffic guidance and warning systems; mobile communications; emergency lighting installations and warning systems; interruption-free power supply; building installations).

4.3.3 Wind energy

Reported RTD expenditures on **wind energy** in 1994 totalled 79.5 million ECU, of which 48 million was contributed by government and 31.5 million contributed by private industries. In 1995 the total amounted to 69 million, of which 42.5 million came from government sources and 26.5 million from private sources. An important role in this research area is played by the German government, which appropriates between 40% and 50% of the total EU government budget on wind power R&D. A significant share of the total is also appropriated by Italy, Denmark, the Netherlands, Spain Sweden and the UK.

Wind energy technology has definitely reached the commercial stage, although much work still needs to be done both to reduce production costs for system components (at industry level) and to increase overall reliability and integration with electric grids. Operation in extreme conditions is also being investigated. In parallel, much work is being done on site characterisation and wind potential assessment to obtain complete mapping of potential sites; on environmental impacts and public acceptance. To facilitate wide diffusion of the technology, standards and certification procedures are being investigated, as well as normative guidelines for localisation of plants. Activities at demonstration level are abundant.

- Technology for wind components: fundamental wind-related problems in aerodynamics: rotor aerodynamics, structural dynamics and load basis, strength of materials: special aerodynamic conditions for wind turbine blades (Denmark); carbon fibre blades (France); blade testing, development of wind turbines; new bearings; low-speed electrical generator with permanent magnets (United Kingdom). Generators with constant frequency output at variable speed (Ireland). Key problems in large-scale wind plants (Germany).
- Integration of wind energy in autonomous power systems (e.g. island grids) or national power grids (Finland, Greece, Ireland, Italy, United Kingdom). Need for backup power: hybrid wind plants (Finland), low-capacity wind turbines coupled with diesel engines (France).
- Storage and control: superconducting storage, control electronics (Finland).
- Increasing attention is being paid to: arctic and offshore wind technologies (Finland), wind farms (Denmark), mass production development of both large and small wind power plants (Finland, Denmark), various applications including desalination; reduction of construction costs, enhancement of performance, life extension for existing designs (Sweden, United Kingdom); design and demonstration of new prototypes, assessment of markets (both domestic and abroad) (United Kingdom).
- Wind potential assessment (e.g. measurement of wind speeds); complex terrain modelling (Greece); energy conversion modelling in wind energy parks (Portugal); wind measurements for the purpose of identification of wind farm sites, characterisation and qualification of sites (France, Greece, Ireland, Italy, Spain, Sweden, United Kingdom).
- Assessment of environmental impacts and problems connected with public acceptance and other non-technical barriers: impact minimisation (e.g. noise reduction and development of siting guidelines) (Italy, United Kingdom),
- Development of standards and certification. National siting regulations are being developed in France and the United Kingdom.

4.3.4 Energy from biomass and wastes

The total RTD expenditure on **energy from biomass and waste** in 1994 was 55.2 million ECU, of which 43.3 million was contributed by government and 11.8 million by private industries. In 1995 the total amounted to 62.2 million, of which 48.5 million came from government sources and 13.6 million from private sources. Significant shares of the total EU government budget for biomass are appropriated in Austria, Denmark, Italy, the Netherlands, Norway, Spain, while the largest spenders are Finland, Sweden and the UK.

On energy from biomass and waste activity seems to be abundant and proceeding in a number of directions. Some countries are interested in energy production from wood and forestry by-products (Finland, France, Greece, Sweden); some have significant resources of peat (Finland and Ireland) and would like to exploit them. Others are more interested in producing and using biomass from short rotation crops (SRC) and agricultural residues (UK, France, Italy, Spain). Finally, all countries are aware of the energy production potential of urban and industrial waste and landfill gas. Technological areas being explored range from biomass gasification to production of liquid biofuels (but the latter are not thought to be commercially viable yet) and to the use of biomass as a solid fuel.

- Evaluation: research and evaluation of the energy potential of biomass crops, agricultural and forest residues for energy and as an industrial feedstock (Ireland); energy crops such as sweet sorghum, *cynara cardunculus, miscanthus sinensis giganteus* etc. on fertile and marginal lands (Greece); evaluation of ecological effects on the ground, flora and fauna (Austria).

- Biomass production. Research on short rotation forestry (SRF) (Austria, UK, Germany, Italy, France, Sweden); wood by-products of the paper industry (Finland). Harvesting and integrated pest management strategies for SRC (United Kingdom, Germany). Studies are performed regarding herbaceous plants such as sorghum and miscanthus (for production of bioethanol), and graminae (Belgium, UK, Italy, Greece). Other energy crops under consideration for the utilisation of marginal land include Cynara Cardunculus, Ricinus Communis, Energy Cane and Elephant Grass, Colza (rape-seed) (France, Greece, Ireland, Italy, United Kingdom). Research is also carried out to improve the competitiveness and environmental impacts of peat (Ireland, Finland).

- Transformation into secondary energy carrier (biogas, liquid or gaseous energy carrier). Gasification of biomass (Denmark, Germany, Italy, Finland, UK): thermochemical conversion (gasification and flash pyrolysis) is also investigated (Belgium, Finland, Germany, Greece, Italy, Spain, Sweden, United Kingdom). Other projects include black liquor gasification for heat and power production (Sweden). Energy valorisation of landfill gas, anaerobic digestion of sewage sludge; fermentation of waste at high temperatures (Ireland, United Kingdom). Production of enzymes for industrial use of agri-wastes/residues (Ireland). Processing technologies for biomass (Germany). Production of liquid biofuels (bioethanol and methanol) for transport. Among the types being developed: rapeseed methyl ester, and ethanol, converted to ETBE and incorporated into unleaded premium petrol (Belgium, France, Italy, Sweden). Colza (rapeseed) oil is also being investigated as a liquid heating fuel (Ireland). Conversion of pulp industry by-products (black liquors, lignine etc.) to liquid fuels and production of fuels from wood or peat by flash pyrolysis is also attempted (Finland). Biochemical conversion. Efforts are made on steam explosion followed by enzymatic hydrolysis (Italy) and also pyrolysis (for instance the Ensyn pyrolysis process for straw in the United Kingdom). Work is also done on the winter performance of biodiesel (Austria).

Further research is carried out on the transformation of lignocellulosic biomass into a solid biofuel easy to feed into boilers, to allow co-firing with coal; on wood pellet production from forestry residues (Austria, Sweden). Demonstration projects for heat generation from biomass (Belgium, France).

- Research on biofuel combustion process ranges from suitable boilers (large and small for residential applications, fed with lignocellulosic biomass) (France) and suitable engines (with vegetable oil) (Austria), to the combustion of vegetable oils and their by-products; handling and drying of biofuels, use of biofuels in small district heating plants and power plants, development of equipment and technology for emission reduction in combustion (Finland). Applications include advanced central heating systems based on biomass and waste, district heating, small-scale CHP. Incineration of biomass alone or mixed with other fossils for power generation (Germany). Attention is paid to the environmental impact of the cycle (inputs, effluents for instance) in Belgium, Germany and the United Kingdom.

- Research is shifting on non-technical barriers, such as uncertainty in evaluating landfill gas resource, planning problems arising from environmental impacts such as dioxin emissions to air, public acceptance of energy-from-waste schemes, assessment of the market for heat from municipal solid waste (MSW) CHP plants, and assessment of emission monitoring equipment, biomass transport logistics, regulatory standards on emissions (United Kingdom). Socio-economic research is also being carried out in Belgium and Finland.

4.3.5 Hydroelectric plants

Reported RTD expenditures on hydropower in 1994 totalled 20.9 million ECU, of which 7 million was contributed by government and 13.9 million by private industries. In 1995 the total amounted to 17.9 million, of which 4.1 million came from government sources and 13.7 million from private sources. Of the total EU government budget for hydropower R&D, the largest shares are appropriated by Norway (60% to 90%), Austria and Spain.

On hydroelectric plants research activity is not very intense. Hydropower is a mature technology and, as the potential for large generating plants is fully exploited, perspectives for further growth of this resource lie in new small and mini-hydro (less than 10 MWe) capacity (Greece, Ireland) or in refurbishing and life extension of abandoned sites (Italy). Research activity in this area can be considered marginal and is limited to countries with poor endowment of domestic energy resources. The only exception is Sweden, where research focuses on security-related problems, public acceptance and methods/technologies for renewal of existing hydropower plants.

4.3.6 Geothermal energy

Total RTD expenditures on geothermal energy in 1994 amounted to 29.6 million ECU, of which 23.5 million was supplied by government and 6.1 million spent by private industries. In 1995 the total amounted to 8.6 million, of which 4.6 million came from government sources and 4.0 from private sources. EU government expenditures in this area concentrate in Germany (>40%), France, Greece and in 1994 in Portugal.

Geothermal energy receives limited attention, mostly due to its small exploitation potential, in Europe. Resources concentrate in southern Europe (Italy, France, Greece, Portugal) but some research is also done in Germany. This potential, however, is larger outside Europe (particularly in some developing countries) and therefore activity continues along the following lines: exploration and drilling techniques including horizontal drilling (France, Italy); reservoir modelling (France); corrosion, deposition and scaling problems (France, Italy); borehole cleaning techniques; the role of bacterial activity and the search for an inhibitor; experiments with bactericide and mixed biocides/anti-corroders (France); power generation from dry steam fields (France, Italy); high-pressure hydraulic injection into boreholes of the hot dry rock; reinjection.

Some work is done on the improvement and optimisation of binary cycles employing organic fluids (Italy). The ammonia technology either in low enthalpy fields or as a bottoming cycle in high enthalpy is being developed (Italy), as well as observation and monitoring techniques for the steam or water levels.

Further work is done on uses and applications of geothermal energy (sea water desalination, heating and cooling of buildings) and to the integration of this energy source with others (Greece).

4.3.7 Advanced energy storage

R&D expenditures on **advanced energy storage** amounted to 5.5 million ECU in 1994 and 4.1 million ECU in 1995, all of which came from public sources. Nearly 100% of these expenditures were made by Germany.

Reported RTD activities concern: storage of energy from renewable energy sources (solar PV) using hydrogen production (Italy); hydrogen technologies combined with solar power (Germany); feasibility studies and preliminary designs of large-to medium-scale superconducting energy storage systems (France, Italy).

4.3.8 Further options

Total EU R&D expenditures on **other renewable options** amounted to 8.8 million ECU in 1994 and 10.4 million ECU in 1995, almost entirely from public sources. Over 50% of these government funds were spent in Spain but significant amounts were also spent in Finland, Portugal and some in the UK.

Concerning this area, less and less attention is being devoted to the technology of wave energy, and that is concentrated in the countries along the Atlantic coast (Belgium, Ireland, Portugal, United Kingdom). Work is on shoreline turbines, variable-speed constant frequency generators with inertial storage capacity.

Another option being studied, however, and the one on which current financial efforts are concentrating, is high-temperature solar energy (Spain).

4.3.9 Cross-cutting technologies

R&D expenditures on **cross-cutting technologies for renewables** amounted to 12.6 million ECU in 1994 and 14.9 million ECU in 1995, all from public sources. Substantial expenditures are reported by Germany, and some by Spain and Norway. Work in this area is reported only by Finland on small-scale electricity technologies; conversion: turbines, generators; storage and control; fuel switching; distribution (grid feeding, decentralised electricity production).

4.4 FOSSIL FUELS

Reported total RTD expenditures on fossil fuels in 1994 amounted to 424.1 million ECU, of which 124.7 million was supplied by government and 299.3 million spent by private industries. In 1995 the total amounted to 518.2 million, of which 124.1 million came from government sources and 394.1 million from private sources. Of the total EU government budget for fossil fuels R&D, the largest shares are appropriated by France (27%), Germany (>10%), Norway (15%) and the UK (about 20%).

The main activities are enhanced oil and gas recovery from existing or marginal fields, new exploration technologies; clean coal technologies, efficient combustion and conversion.

Research on fossil fuels is usually carried out by the industries (both private and government owned) or in those countries where significant fossil fuels resources are found (Norway, UK, for oil and gas; Germany, UK, Spain for coal; Greece for lignite, etc.).

4.4.1 Solid fuels extraction, preparation and transport

Reported total RTD expenditures on solid fuels extraction, preparation and transport in 1994 amounted to 3.2 million ECU, of which 3 million was supplied by government and 0.26 million spent by private industries. In 1995 the total amounted to 2.7 million, of which 2.3 million came from government sources and 0.4 from private sources. The governments that spend the largest budgets in this technology area are the British (around 30%), Spanish (22%), French and German (15% each).

Concerning solid fuels, some European countries (Germany, UK, France, Belgium, Spain, Greece) have solid fossil fuel resources (coal, lignite), but they are either of low quality or present high extraction costs, or both. The coal industry is being downsized in those countries where it had survived thanks to heavy government subsidies. However most countries aim at maintaining a pool of national expertise and technological know-how in this field, mainly in view of exploiting opportunities in the world coal market. This is true both for exploration, extraction and beneficiation technologies and for transformation technologies (gasification or direct combustion).

Some R&D activity is thus being carried out on the following: Coal exploration and extraction, strata control in coal mines, improved mine design to reduce rock stresses in underground tunnels (United Kingdom); underground (in-situ) coal gasification (Belgium, Spain); in-seam seismic exploration techniques (United Kingdom); safety and control of methane emissions; mine climate control (United Kingdom); coal preparation; dry beneficiation and cleaning (United Kingdom); coal handling and transport (Italy, United Kingdom).

4.4.2 Clean technologies for solid fuels and gas

Reported total RTD expenditures on clean technologies for solid fuels and gas in 1994 amounted to 51.2 million ECU, of which 30.6 million was supplied by government and 20.5 million spent by private industries. In 1995 the total amounted to 39.54 million, of which 26.6 million came from government sources and 12.9 million from private sources. Of the total EU government budget for clean-coal technology R&D, the largest shares are appropriated by Germany (over 40%), the UK (22-25%), Spain (at least 20%) and France (around 15%).

Research in this area is mostly in development and demonstration, including:

- advanced cycles: pulverised coal boiler (for SO_2 and NOx emission reduction) (France); fluidised bed boiler with atmospheric circulation (France), or pressurised (Sweden); gasification and combined cycle (France), air-blown gasification (United Kingdom);
- development and demonstration of low-NOx burners, reburning procedures (mainly in the cement industry) (Greece). Selective non-catalytic reduction of NOx for retrofitting of existing plants; demonstration activities for the development of innovative denitrification systems and catalysers (Italy);
- flue-gas cleaning (Denmark). For SO_2 reduction the following are investigated: ceramic filters, calcium activation, hot IGCC-gas cleaning (Spain). Commercial SO_2 reduction procedures: wet and dry injection of lime; Ca/S rate; kinetics reaction (Spain). Other processes not using lime (ABB Flakt-Hidro process - sea water scrubbing); solid wastes removal by plasma technology (Spain).

On **conventional steam cycles** RTD activity is being developed in the following technologies.

- Expanded steam tunnel experimentation for calibration of two-phase flow, study of turbine blades and improvement of condensers (Italy).
- Coal combustion research in conventional utility power generation largely focused on NOx reduction: testing air-staging and reburning techniques (United Kingdom). Problems of slagging and fouling; mathematical modelling of power station boilers; effect of particle size on coal combustion; reduction of SO_2 by dry sorbent injection; neural networks for NOx control; modelling of NOx formation (United Kingdom).

On **advanced cycles**, research reported includes the following.

- Coal conversion: pyrolisis, gasification and combustion in fluidised bed; physical and chemical parameters of oxidation during combustion (Belgium); underground coal gasification (UCG-UGE) (Spain); coal liquefaction (United Kingdom).
- Much demonstration activity takes place in Spain: circulating fluidised bed combustion boiler (CFBC); pressurised fluidised bed combustion plant (PFBC); integrated gasification of coal combined cycle (IGCC); study of problems associated to plant scale-up (protection of the turbine, cyclone cleaning and ash removal systems); pressurised fluidised bed gasifiers and a low-NOx gas turbine combustors for use in the air-blown gasification cycle (United Kingdom).
- Study and development of components for gas turbines: steam raising, gas turbine improvement; materials development; cycle performance; system development and component interaction (United Kingdom). To improve conversion efficiency, work is being done on advanced and ultra-supercritical plants and evaluating materials and technologies for those plants (Italy). Externally fired combined cycle (EFCC) is also investigated (Italy).

- Development and testing of low-NOx burners for coal and oil. Post-combustors for reburning and combustion systems that reduce the formation of SOx, NOx and ashes; coal reburn process simulators; gas reburn systems (Italy). Low-NO_x multi-stage burners with sorbent injection (Spain). Gasification with cyclone separators; hot gas clean-up (United Kingdom).

4.4.3 Generic combustion

Reported total RTD expenditures on generic combustion in 1994 amounted to 13.1 million ECU, of which 9.2 million was supplied by government and 3. 9 million spent by private industries. In 1995 the total amounted to 11.5 million, of which 7.7 million came from public sources and 3.8 million from private sources. The governments that spend the largest budgets in this are the Finnish (from 50% to 80%) and the Spanish one (from 17% to 48%).

Research is reported in the following areas: new burners, reburning and other advanced combustion techniques; high-temperature testing of combustors for gas turbines; solid fuel (coal and biomass) combustion tests in fluidised beds; combustion/gasification technologies, flue gas treatment and materials for new components (Sweden); emissions reduction during combustion (Portugal); mathematical simulation of combustion processes using high performance, massive parallelism supercomputers (Italy).

4.4.4 Hydrocarbons (oil and gas, oil shales and tar sands)

Reported total RTD expenditures on hydrocarbons in 1994 amounted to 329.9 million ECU, of which 74.8 million was supplied by government and 255.1 million spent by private industries. In 1995 the total amounted to 436.9 million, of which 77.5 million came from government sources and 359.4 million from private sources. Of the total EU government budget for oil and gas R&D, the largest shares are appropriated by France (nearly 40%), the UK (about 18-20%), Norway (over 23%), and the Netherlands (another 6-14%).

Research in this technology area concentrates on reducing the cost of hydrocarbons production through improved exploration methods, extraction systems capable of enhancing resource recovery and safer transportation systems. In all phases of this cycle, the effort to reduce environmental impacts and to reduce environmental risk is becoming more and more relevant.

- Exploration. R&D is focused on seismic inversion, reservoir characterisation (Denmark); interactive sequential forward modelling software for use in hydrocarbon exploration (Ireland); geoseismic exploration while drilling (Italy); three-component seismic methods (also considering transversal waves) to identify fractures at depths greater than 3,500 m. (Italy); seismics reaching through salt deposits (requiring the massive utilisation of supercomputers); modelling methods that allow reaching the most productive points of a deposit through horizontal drilling (Italy).

- Extraction. Development of offshore technologies for oil and gas is being pursued: in particular: multi-phase pumping (Italy). Optimisation of the exploitation of deposits with improved washing techniques for asphaltanes (including basic research on their precipitation) (Italy). Extraction techniques for heavy crudes (in particular with water-steam injection). Biomarkers for crude oils (Italy). Oil recovery mechanisms in low permeable chalk reservoirs and naturally fractured reservoirs; cost effective concepts and facilities for development of marginal fields (Denmark).

- Transport. Developments in transportation of gas by pipelines are continuing on technologies for maintenance, diagnostic and repair (Italy); optimisation of the gas pipeline and distribution network operation and maintenance (also through expert systems), improved monitoring operations (Spain). Cost reduction in network renovation through new materials and construction systems (Spain). Increase in operating pressure for long distance, land-based pipelines (Italy). Improvements on the monitoring and diagnostics of pipelines obtained in connection with the pumping of heavy hydrocarbons and tars (Italy). Emergency management in the transportation of hydrocarbons, both by pipelines and by ship (Italy). Development of systems to reduce emissions of gas into the atmosphere, improvement in gas detection systems, and study of gas dispersion (Spain).

Reported total RTD expenditures on **refining** in 1994 amounted to 50.65 million ECU, all of which was spent by private industries. In 1995 the total amounted to 33.80 million, all from private sources.

Main fields of interest in the refining sector are given below.

- Conversion:. Innovative refining methods: catalytic cracking, the utilisation of dispersed catalysers for the conversion of heavy oils and residues (France, Italy); the recycling and life extension of such catalysers (Italy); deep conversion of heavy oil (France, Italy); hydrocracking (France).
- Motor fuels: development of new reforming catalysts for premium petrol and diesel oil (France); reformulation of petrol and diesel fuels (Italy); vehicle exhaust catalytic converters and production of highly desulphurised diesel oil with a low content of aromatics allowing the use of catalysed oxidising exhaust to abate particulate (Italy). For petrol work is being done on the transformation of C7-C9 straight run petrol to high octane petrol without producing aromatics (i.e. finding an alternative to catalytic reforming) (France). For diesel the problem of low cetane of naphtenic cuts (obtained after hydrogenation of polynuclear aromatics) is being investigated (France).
- Basic petrochemicals: production, treatment and transformation of light olefins and aromatics; gas treatment aiming at higher hydrogen consumption in the refinery or reduction of sulphur rejection (France); chemical conversion of natural gas to liquid fuels or high-quality synthetic routes (e.g. improved catalysts for Fischer-Tropsch synthesis) (France, Italy) aimed at long-term large-scale replacement of oil, as well as to exploit marginal deposits or associated gas; definition of new catalytic systems for naphtenic ring opening, selective isomerisation of paraffins, and more selective aromatisation of LPG; separation techniques with adsorption and permeation membranes (France).
- Environmental aspects: Sulphur extraction from oil by biotechnological methods has proven too expensive and has been abandoned. Utilisation of refinery-derived tars for gasification and electricity generation (Italy). Environmental effects of gaseous, liquid and solid wastes and noise are also investigated in Spain as well as plant safety improvements and safer handling and distribution of oil products.

4.4.5 Storage

In this area R&D expenditures reported in 1994 amounted to 0.08 million ECU, mostly from the public sector and all spent by Spain.

4.4.6 Cross-cutting technologies

R&D expenditures reported in this area in 1994 amounted to 4.1 million ECU and in 1995 to 6.4 million, all of which in the public sector and nearly all spent by Spain and Sweden.

4.5 CONCLUDING REMARKS

The information so far collected on the energy R&D activities carried out (mostly by public research institutions and agencies) and areas of interest in the EU countries, should be viewed with some caution, due to the problems mentioned at the beginning of chapter 4.

On the other hand, owing to the level of detail of information requested from the national teams and reported here, it is easy to lose sight of the complete picture.

To close this chapter, an effort to pull together all this material and to identify a pattern in this picture seems indeed necessary. In this direction some general considerations can be made.

- In the area of non-nuclear energy technology very few technological breakthroughs have been made in the last 10-15 years: this fact is clearly apparent from the information collected on R&D activities in the EU. If we exclude fuel cells (a relatively old idea) and hydrogen, there are almost no "new" concepts in the pipeline.
- Most of what is currently being researched is so-called "evolutionary" (as opposed to "revolutionary") technology, that is, incremental improvement of existing technology – although over time incremental improvements of existing technology can add up to significant improvements.
- Furthermore, a large portion of these improvements are simply spillovers from research that has been carried out in other scientific and technological areas, i.e. not done for energy purposes.
- The focus of research being carried out in EU countries, with very few exceptions, seems to be on improving existing technology in the following main directions:
  1) exploiting the benefits of network integration (grid interfacing for renewables, improvement of power transmission systems, intermodality in transport) and of systems integration of specific technologies (in buildings, vehicles, but also in terms of land use planning for transport systems);
  2) re-engineering production processes with increased attention to environmental impact mitigation in general, through the use of more efficient new materials, new cross-cutting technologies, and through recycling;
  3) utilisation of industrial and urban waste for energy production;
  4) increased use of process control and monitoring technologies (both in manufacturing and energy extraction, production and transport);
  5) increase the capacity to use, manipulate and model information and data to increase the success rate in exploration activities;
  6) improvement in combustion technologies (both for increased efficiency and cleanliness);
  7) improvements in storage technologies;
  8) cost abatement in the industrial production of energy systems and components;
  9) improved safety features of energy systems;
  10) increased attention to non-technical barriers to the deployment of new energy technologies as well as to technology assessment and other socio-economic aspects.

How do we evaluate these trends and what are their policy implications?

Some of the reasons have already been discussed in the previous chapters (low energy prices and increased competition in the energy industries, consequent change in priorities by the governments, by businesses and the general public).

On one hand, whatever the reasons behind these research objectives, they remain valid *per se*: for example, improved system and network integration remains a desirable objective because it has interesting potential for increased energy efficiency. But in order to be encouraged, this type of research needs specifically designed policies, which are not necessarily limited to increased government funding.

A mix of research, industrial and fiscal policies instruments may be needed:

- funding of specific projects in cross-cutting technologies with interesting energy applications in more than one area;
- government-sponsored consortia and partnerships with industry to encourage very focused research;
- tax breaks for research carried out by the private industry on well-identified technologies;
- more severe performance standards for new energy-using investment goods;

- market support measures such as subsidies or tax breaks (limited in time) for the purchase of more energy-efficient systems, consumer information campaigns, etc.

On the other hand the increasing focus on short-term research would not be a matter for concern, per se, if it was not for:

a) the need to address the long-term issues of greenhouse gas emissions reduction and our dependence on fossil fuels;

b) the fact that, while government energy R&D has been falling for the last 15 years, from 1991 to 1995 (last year for which data are available) total public and private R&D spending in all scientific and technological areas in real terms has increased little (if not actually declined) in the OECD countries.

Assuming a positive relationship between R&D expenditures and technological innovation (and everything else remaining equal), this second fact may imply that in the future we would have less reason to expect spillovers from other technological areas into energy technology at the same rate as in the recent past.

Both a) and b) give some ground to the argument that there is a need for continuing (and increased) government involvement in energy R&D, especially in basic and long-term research to allow the identification of new, promising concepts and the development of new technologies capable of satisfying at least part of our future energy needs in an environmentally sustainable way.

REFERENCES

EUROSTAT: *Government Financing of Research and Development*. Yearly data. Various issues.

European Commission: *European Report on Science and Technology Indicators 1994*. EC- DGXII, 1996.

OECD/International Energy Agency: *IEA Energy Technology R&D Statistics*. Paris, 1997.

OECD: *Main Science and Technology Indicators*. Paris, 1997/1 and 1997/2.