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Industrial Engineering in Catalonia: 1996–2002*

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Industrial Engineering in Europe and the United States refers fundamentally to the engineering of productive processes. This field coexists with other branches of engineering, such as Mechanical, Electrical and Chemical Engineering. By contrast, in Catalonia and Spain, Industrial Engineering considers all of these fields as a whole.

For more than a century, Industrial Engineering was the only branch of higher-level engineering in Catalonia that had university status, which made it the only field of Engineering able to meet the needs of industrial and business activities. In the last few decades, this situation has changed due to the establishment of other types of engineering faculties, new qualifications, and to the evolution of science faculties, some of which now have engineering departments in areas of Industrial Engineering.

Research corresponding to Industrial Engineering can best be evaluated from a conventional viewpoint, which, for this report –part of a collection of 26 reports assessing all fields of research in Catalonia– consists of the following four fields (the same as in the first report covering 1990–1995):

- Mechanical Engineering and Materials Engineering
- Electrical and Energy Engineering
- Chemical Engineering, Textile and Paper Engineering, and Environmental Industrial Engineering
- Industrial Management

Defining these fields does not solve the problems of their delimitation, with respect neither to the types of research carried out in each of them nor to the shared interests among them. Nonetheless, the data obtained for human resources, economic resources, and research results in Industrial Engineering also do not make up a good starting point for constructing, together with data from other reports, a broad range of information concerning the state of Industrial Engineering in Catalonia. However this is not the purpose of an analysis done by fields. Moreover, the administration is already aware of the broad-range data, which are obtained by analyzing the entire data set and thus free from the unavoidable uncertainties that arise by delimitating fields of research.

The objective of this report is thus to reveal the strong and weak points of research in the field defined as Industrial Engineering. In order to do this, it is essential that the data obtained from its different component areas be reliable, which is not easily achieved. We experienced similar difficulties during the preparation of the first report. Even if, at present, access to the data has been facilitated by the existence of web pages from the administrations and the universities, the data are not always complete or updated. In addition, in the time between the last report and this one, new research groups and research centers have been set up, most of them in new universities, which are not specifically technical and where engineering research is often carried out by groups that participate in activities more suitably evaluated in other reports. Concerning the difficulties in acquiring data, we must acknowledge the work carried out by the documentalist, Mr. Llorenç Arguimbau, at the IEC, as well as the documentary support provided by the Technical University of Catalonia (UPC) services related to research.

Consideration of general frameworks of research in Catalonia, Spain, and Europe

There are two points of view when evaluating research activity within the general framework of research in Catalonia, Spain, and Europe. First, financial support, which comes from these three sources, can be examined; such data, for the most part, is available in databases. Second, a comparative evaluation by means of a set of indicators can be made.

Not all indicators prove significant when evaluating research in a restricted field. Macroeconomic indicators, such as percentage of GDP (gross domestic product) dedicated to research in different countries and in Spanish autonomous regions, are useful in a comparative analysis of countries or regions, but not of a restricted field. It would be indeed interesting to apply this approach of macroeconomic indicators to

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compare the indicators describing the state of a particular field of study, since it would compare the intensity of research in Industrial Engineering in Catalonia with that in Spain, Europe, and other Spanish autonomous regions. This comparison, however, is not possible because equivalent indicators for the field in Spain, Europe, etc. are not available.

Thus, the consideration of external indicators was limited to the ones that serve as reference values for those calculated in this report. As a relative indicator for human and economic resources we have considered:

- Average annual expenditure (in thousands of Euros) in research per investigator And as relative indicators for scientific output we have considered:
- Average annual number of theses per investigator
- Number of theses per million Euros spent in research
- Average annual number of indexed articles per investigator
- Number of indexed articles per million Euros spent in research

When comparing indicators, the way in which the intervening factors were evaluated should be taken into account. Doctoral theses and articles in indexed journals are two of the multiple criteria that reflect human and economic resources.

The evaluation of economic resources was not included in the report, nor were resources obtained for continuous training activities (master degrees and postgraduate courses) or expenditures corresponding to the salaries of university professors. Given that the focus of this report is research, it was not considered necessary to include training activities or those groups or research centers whose main activity is related to training. Regarding professors' salaries, it would have been reasonable to include them if a comparative study of research in industry –where it is standard to take into account the salaries of research staff– had been made.

Difficulties in obtaining information have limited our calculations for public centers, which for Industrial Engineering in Catalonia, belong exclusively to universities. In such cases, indicators related to expenditures will have a greater impact if they are limited to those concerning resources additional to professors' wages, such as those associated with projects, agreements, interns, subsidies, etc. If the staff expenditures are not included, this indicator has a value of zero as its lower limit, which would correspond to a group or center that has had no additional income –probably due to the fact that it is not dedicated to investigation, although this aspect is evaluated through other indicators. If staff expenditures are considered, their impact would be equal to a half to two thirds of either the reference values or those of other groups in the field that take in a significant amount of additional economic resources for research.

As for human resources, the number of investigators in the universities was determined according to the EDP ("equivalent to full dedication"). In, for example, state-supported projects, 1 EDP corresponds to a professor from the research and teaching staff (PDI) with full-time dedication (TC); however, in some statistical analyses, this level of dedication is defined as 0.5 EDP. This report used the former definition, which made it necessary to adjust general indicators previously calculated with the latter one.

The figures in the *Annual R+D+I report for Catalonia* for the year 2000 (published by the Government of Catalonia in the year 2003) were taken as the reference values. Since these values were calculated according to 1 PDI working TC = 0.5 EDP, they were adjusted by dividing by 1.8 the values relative to Catalonia, and by 1.5 those relative to Spain (given the different PDI and research staff proportions in Catalonia and in Spain). The adjusted values systematically employed in several sections of this report are provided in the following table:

	Catalonia	*Spain*
Expenditure per investigator (adjusted) in thousands of Euros		
• Public sector (university + civil service)	23.17	31.63
• University only	21.68	26.85
Results per investigator (adjusted)		
• Theses/investigator	0.063	–
• Articles/investigator	0.318	0.274
Results per million Euros		
• Theses/million Euros	3.56	–
• Articles/million Euros	13.75	8.66

Report structure

For each of the fields studied, the report includes the following sections:

1. Characteristics of the field
2. Information sources
3. Research groups and centers
4. Human resources
5. Economic resources
6. Results
7. Conclusions and recommendations

The main objective of the report was to identify the strengths and weaknesses of research in Industrial Engineering. Since these are most likely to be specific to each of the fields of study, the analysis was carried out so as to reach conclusions for each one, thereby revealing potential differences between them.

In the first section, the specific traits of research in each field, and how these, in turn, influenced the development of this report are discussed. The difficulties faced in delimiting a field and obtaining its corresponding data also have been noted.

In the section Research Groups and Centers, the precise frontiers that define each field are specified, as are the subdivisions created in order to obtain a realistic perception of the different situations faced by researchers, since an overly broad global analysis could conceal some data. Since it was not always possible to obtain data with the same degree of analytical detail for all the research groups and centers, some analyses were restricted, when appropriate, to the more highly documented groups, given that, due to their size, they represented an important proportion of the field. It was preferable to include this restricted analysis rather than to carry out an imprecise evaluation or to omit it out completely. The restricted analyses often refer to the UPC, due to data accessibility reasons and because the total amount of participation of its groups was very significant.

In the section Human Resources, there are some subtle differences in the evaluation of the number of investigators in the different fields, since in some groups and centers part-time professors are limited to teaching whereas in others they are also involved in research. In each field, it was assumed that in all cases 1 PDI working TC = 1 EDP.

In the section Economic Resources, the analysis of some fields was restricted to the UPC, due to lack of access to corresponding data from other universities. In this section, the indicator "expenditure/investigator" for each of the areas and for the field as a whole is described.

In the Results section, besides concentrating on theses, articles published in indexed journals, and the other indicators described in the Introduction, the specific traits of each field led us to consider various interesting correlations when conclusions were drawn. Thus, whereas for one field the ratio between number of articles and theses is shown, for another, the relation between the number of indexed articles and the operative lines of research was determined.

Analysis of research activity in each of the studied fields

As in the previous report, the analysis of research activity is presented separately for each of the four fields considered. Although the same basic pattern for the acquisition and analysis of data was followed, for each field, subdivisions that illustrated their particularities as well as their strengths and weaknesses were also included.

The collective approach is recaptured in the section Concluding Remarks and Recommendations, in which generalizations based on complete as well as partial results obtained through the research indicators are presented. In addition, this section presents the final considerations and conclusions drawn from each field, synthesizes this information, and formulates recommendations for the field of Industrial Engineering as a whole.

Mechanical Engineering and Materials Science and Engineering

Characteristics of the field

Mechanical Engineering and Materials Science and Engineering are two fields of Industrial Engineering that have evolved in very different ways. The latter is characterized by intense research activity, well above that of the former. This is due to the fact that, in the field of Materials Science and Engineering, there are numerous practical applications, which provides a strong motivation for research in this area.

Mechanical Engineering has been historically associated with the design of machinery (intended for a wide industrial sector) and with the development of products and manufacturing processes. In the field of Mechanical and Materials Engineering (abbreviated as EM-M), the current structure of the university can be classified into four main areas:

- Materials Science
- Machines and Vibroacoustics
- Fluid Mechanics
- Modeling of Continuous Media

The area of Machines and Thermal Motors, which is sometimes classified as part of Mechanical Engineering, is included in the Energy Engineering section of this report.

The Materials Science (CM) area comprises studies of the mechanical properties of different structural materials (metals, ceramics, polymers, composites, and biomaterials) as well as their behavior regarding fracture and fatigue, from the experimental, simulation, and modeling points of view. Research into functional materials –those which are of interest for reasons other than their mechanical properties (conductors, superconductors, etc.)– was not included in the area of CM, rather in the report on Physics.

The study of the behavior of structural materials requires the development of methods and numerical algorithms, which in themselves constitute an area of investigation powerful enough to be considered independently, is referred to here as Modeling of Continuous Media (MMC).

Machines and Vibroacoustics (MV) corresponds to what in the past was generally called Mechanical Engineering. For this area, the main topics are the study (design, simulation, and construction) of mechanisms and machine elements as well as the creation of noise and vibrations in machines and industrial surroundings. Acoustics are also included, since they tend to be studied by the same groups studying mechanical vibrations.

Fluid Mechanics (MF) includes all areas related to mechanical systems with oil-hydraulic governors, turbomachines or pneumatic components. Flux and turbulence simulations can be considered as part of MF or MMC, the latter being used in this report. It should be noted that linked to Fluid Mechanics there is an area of study that deals with water technology and fluid management. Given that it belongs to environmental study and research, it was excluded from this report.

Information sources

This report was generated from quantitative data regarding resources –human and economic– and the results of research activities. While these data should be available as links on the web sites of the different universities, these links do not always exist (as is the case for the University of Gerona); in other cases, they exist but + are not regularly updated. In the case that they do work properly, they do not always offer the data of interest (for example, it is generally difficult to gain access to information concerning the funding of projects and agreements, the period to which they correspond, etc.), or else the data are of such global nature that it is impossible to extract the section that deals exclusively with EM-M. Directly contacting the departments administering postgraduate studies and research also does not always leads to obtaining the desired information.

For all these reason, more than one source was consulted to create a reliable map of EM-M research in Catalonia. The data were systematically cross-checked, and when discrepancies were detected, the highest or more favorable value of the parameter being evaluated was chosen as the representative indicator.

The data basically come from:

- University web pages (those of the postgraduate and research units of the universities, departmental web pages, and web pages of the –usually interdepartmental– research groups)
- Web pages of the different non-university research groups (associated or not with universities)
- Science web pages (databases covering all the publications in indexed journals for all scientific areas)
- Ministry of Universities, Research and Information Society (DURSI) web pages

Research groups and centers

Research activities in the EM-M field are divided between the industrial sector and what is known as "research units". The latter includes a variety of centers and groups, most of which are associated with public institutions, whose involvement in research differs greatly.

The R+D directory of the DURSI contains the most complete listing of research units in Catalonia. Nonetheless, in relation to this report, it poses two problems. In the first place, units are grouped in different categories that do not have a null intersection. Thus, some laboratories that belong to university departments are found under "Research Groups" and under the generic denomination "Departments". Furthermore, the same laboratories can also be listed under "Technological Innovation Networks". The second and most important problem is that the dossier for each organization does not contain information about its level of involvement in research activities. Instead, the organizations are often classified as research units, centers or groups, including those mostly involved in development or training, or which provide technical engineering services.

The type of research depends on the EM-M area. For example, given that the field of is more theoretical than the others, it is logical that its research is carried out in university centers, whereas research carried out in fields is more directly related to the industrial sector, particularly that of MV.

Regarding the industrial sector in general, it should be taken into account that the EM-M-related companies vary greatly in size. In addition to the very large companies comprising the automotive industry, there are many small companies that supply components; and obtaining a complete list of all of them is difficult. Furthermore, obtaining data about research developed in industry is also complicated: sometimes is the data are protected by confidentiality clauses, in other cases, activities that are actually concerned with development and production are presented as research.

In the year 2002, the UPC and the Technical University of Madrid created the Investigation, Development and Technological Innovation Accrediting Agency (AIDIT). This is an independent organization whose main activity is to register the R+D projects of companies from all over the country. Its first years in existence have been a trial period with the objective of obtaining the accreditation to begin registration in the year 2003. Hence, data obtained from AIDIT are not significant yet (although they will be essential for future reports). For this reason, the focus of our report has is the university centers.

In Catalonia, there are five universities that include one or more areas of Mechanical Engineering:

- Technical University of Catalonia (UPC)
- University of Barcelona (UB)
- University of Gerona (UdG)
- University Rovira i Virgili (URV)
- University of Lleida (UdL)

At the UdL, EM-M (which is included in the Department of Computer Science and Industrial Engineering) is very recent, and therefore its scientific output is scarce and not representative of what it will be in the near future. For this reason, the corresponding data were not included in the report.

The level of involvement in EM-M research in each of the other universities greatly differs. At the URV, only MF research is carried out by an entire research group (ECoMMFiT: Experimentation, Computing ,and Modeling of Fluid Mechanics and Turbulence) of the Department of Mechanical Engineering, and at the UB the only research developed is in CM, in association with the Department of Chemical Engineering and Metallurgy, and the boundary that divides this department's output devoted to CM vs. other areas of research, could not be precisely defined. In the end, all data related to the area of Materials Science and Metallurgic Engineering from this department were assumed to be relevant to the CM branch (even if, for example, the titles of some of the publications reflect a greater relevance to Chemical Engineering than to CM).

At the UdG, EM-M research is spread out over different, interdepartmental research groups, although not all branches of research are included. It should be taken into account that the departments involved have all been created recently (the Physics Department has been in existence since 1998; the Department of Mechanical Engineering and Industrial Construction since 2001).

The UPC is the only center where all the branches exist. It is also the university with the most human resources and broad-based financing, and with the most complete information regarding indicators. For this reason, of the four centers, it is considered the most representative, and for some aspects it is analyzed separately from the others.

Table 1 summarizes the relationship of each university groups to EM-M, as declared on the DURSI web page. Table 2 lists those not belonging to any university (regardless of whether they are affiliated with them or not).

Data from the centers included in Table 2 were not included in the calculations for the research indicators, as they were considered to not be sufficiently objective (number of investigators, research publications, etc.). What follows, therefore, is a short summary of each of these organizations:

– CLM is one of the centers belonging to the Test and Research Laboratory (LGAI Technological Center), whose objective is to provide industry with technological support. CLM has two sections: one for engineering and one for innovation. The former offers technical engineering services and the latter includes "pre-competitive investigation". Unfortunately, its web page does not offer any information regarding the results from the latter.
– CIM is a flexible manufacturing laboratory created in 1990 by the UPC and the Catalan Institute for Technology (ICT) with the purpose of providing the industrial sector with support in the field of new production technologies. Its

Table 1. Departments and university groups in the field of Mechanical Engineering and Materials Science and Engineering.

University	*Departments involved*	*Area*	*Category*	*Group*
UPC	Materials Science and Metallurgy (702)	CM	GRS	Materials Fracture and Fatigue
		CM	GRS	Structural Materials, Simulation and Biomaterials
		CM	GRS	Polymer Technology and Composites
		CM	XT	Light Alloys and Surface Treatments Design Center (CDAL)
	Mechanical Engineering (712)	MV	–	Industrial Equipment Design Centre (CDEI)
		MV	–	Mechanics and Vibroacoustics
		MV	XT	Laboratory of Acoustic Engineering and Mechanics (LEAM)
	Fluids Mechanics (729)	MF	XT	Laboratory of Oil-hydraulic and Pneumatic Systems (LABSON)
		MF	XT	Industrial and Fluid Dynamics Diagnosis Center
	Materials and Structures Resistance in Engineering (737)	CM MMC	GRS	Materials and Structures Resistance in Engineering, Roads Section
UB	Chemical Engineering and Metallurgy	CM	–	Materials Science and Metallurgic Engineering
UdG	Mechanical and Industrial	CM	–	GRMT (Materials and Thermodynamics)
	Construction Engineering	MV	–	AMADE (Analysis and Advanced Materials for Structural Design)
	Physics	MV	–	GREPP (Process, Product, and Production Engineering)
		MF	–	EFLUIT (Fluids and Transport Engineering)
		CM MMC MV	XT	Materials, Structures and Processes Innovation Center
		MV	XT	Center of New Products Innovation and Conceptual Development
URV	Mechanical Engineering	MF	GRS	ECoMMFiT (Experimentation, Computing and Modeling of Fluid Mechanics and Turbulence)

Table 2. Non-university groups in the field of Mechanical and Materials Science and Engineering

Area	*Category*	*Group*
CM	XT	Laser and Metallurgy Center, CLM (of the General Assay Laboratory, LGAI)
MV	–	CIM Center (linked to the UPC)
CM	MV	R+D Reference Center for Advanced Production Techniques, CERTAP
MMC	XT	International Center for Numerical Methods in Engineering, CIMNE
MMC	GRS	Numerical Methods in Continuous Mechanics and Structures Group (part of the CIMNE; linked to the UPC)
MV MF	– –	Institute of Applied Investigation of Automobiles, IDIADA (linked to the UPC)
MV	GRS	Mechanic Textile Systems and Processes Group, INTEXTER (linked to the UPC)
CM	–	Institute of Materials Science of Barcelona (CSIC)
CM	XT	Catalan Center for Plastics (linked to the UPC)

main activities include the improvement of product and manufacture processes, training and research –usually in collaboration with university groups– of lines of research related to the CIM.

- CERTAP is one of the centers "without walls" created by the Government of Catalonia. Such centers bring together already-existing research teams belonging to different institutions in order to promote group work and optimize resources from complementary groups. At present, CERTAP comprises15 research groups and more than 200 investigators. Its field of work is the research and development of advanced production technologies. One of is main objectives is technology transfer to companies.
- CIMNE'S membership consists of scientists from all over the world, most of whom, however, simply provide support to the entity through their own prestige. One of the main activities of the CIMNE is training, but research is not excluded, as evidenced by the existence of a consolidated research group: Numerical Methods in Continuous Mechanics and Structures. The research staff for this group belongs in its totality to Department 737 at the UPC, thus explaining why it is treated as a university group and not separately.
- IDIADA's work is confidential and thus its own research (not carried out especially for industrial clients) cannot be distinguished from development.
- INTEXTER's web page openly explains its research activity, such as the existence of a consolidated research group, the Mechanic Textile Systems and Processes Group. This report has considered INTEXTER as part of the field of Chemical, Textile and Paper Engineering and Environmental Engineering, due to its specificity.
- Institute of Materials Science of Barcelona (CSIC) research, although catalogued in the CM area, is more related to Materials Physics than to Materials Engineering, and thus is not included in the report.
- Catalan Plastic Center is considered to be a university center because an important proportion of its personnel belongs to Department 702 of the UPC.

Human Resources

All of the personnel associated with each group or university department cannot be considered as human resources; for example, administrative staff. In addition, research and teaching staff (PDI) employed on a half-time basis (TP) are usually involved exclusively in pedagogy. Thus, three categories were defined: (1) investigators (TC PDIs), (2) interns (i.e., students completing a doctoral thesis or carrying out the research of a PDI member), and (3) others (TP). The last group was not included in calculations of relative indicators of results.

Quantitative data concerning human resources were obtained with varying precision, depending on each center. For this reason, a detailed view of the number of investigators, interns, and other support personnel (separately) for the years 1996–2002, was only available for the UPC. In other cases, we were only able to determine the number of people in each group for the year 2003, and not always according to the classification of investigators, interns, and support personnel. The personnel in this last case was included under the category "investigators".

There are two research groups that deserve special mention: (1) Materials Science and Metallurgic Engineering of the Department of Chemical and Metallurgic Engineering of the UB, and (2) the Department of Material and Structure Resistance at the UPC (Engineering, Department 737). In both cases, the personnel is involved in several scientific areas (not necessarily in the EM field). It was therefore not possible to separate the investigators in that group from the total number of investigators, i.e., those who only involved in CM or MMC. From a strict point of view, the percentage of time that each of investigator dedicates to CM and MMC should be calculated in order to adjust the number of investigators (and all the personnel involved in research) accordingly to this percentage. However, this was impossible to do given the available data; therefore, a representative number from each category was taken based on the total number of people in each research group. This produces imprecision in the relative indicators considered in the results section (the number of theses per investigator or the number of publications per investigator, for example). Nonetheless, and particularly regarding data related to publications, the indicators were adjusted, when possible, to provide more realistic results. Since 76% of the total –important– publications from Department 737 dealt with MMC, and 24% with CM, these percentages were applied to the figures for the department's research staff. Table 3 and Fig. 1 summarize human resources, quantified for the UPC; the average values were previously adjusted. Table 4 and Fig. 2 provide the same information for the other universities (UB, UdG, and URV). Figure 3 compares human resources between the studied period and that of the previous report (1990–1995). It was not possible to determine the number of investigators (EDPs) in the previous report, so that Fig. 3 refers to total personnel. It shows

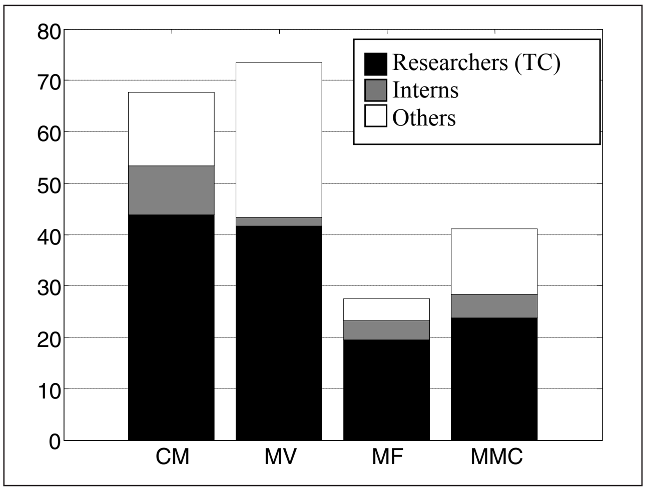

Figure 1. Annual average amount of human resources expressed in number of persons (full-time [TC] researchers, interns, and other support personnel) allocated to this area for the Technical University of Catalonia (UPC) during the period 1996–2002. The data were classified with respect to the four main areas of Mechanical Engineering: Materials Science (CM), Machines and Vibroacoustics (MV), Fluid Mechanics (MF), and Modeling of Continuous Mediums (MMC). Data from the UPC's Dept. 737 (Materials and Structures Resistance in Engineering) were divided into areas MMC and CM according to the percentages mentioned in the text.

Table 3. Technical University of Catalonia: Mechanical and Materials Engineering

Human Resources (average between 1996 and 2002)	*CM*	*MV*	*MF*	*MMC*	*Total*
Researchers	43.81	41.67	19.5	23.69	128.67
Interns	9.48	1.67	3.67	4.69	19.51
Others	14.33	30.17	4.33	12.67	61.50

Table 4. UB, UdG, URV: Mechanic and Materials Engineering

Human resources (year 2003)	*CM*	*MV*	*MF*	*MMC*	*Total*
Researchers	11 (UB) 6 (UdG)	19 (UdG)	2 (UdG) 8 (URV)	–	46
Interns	–	–	–	–	–
Others	2 (UdG)	7 (UdG)	–	–	9

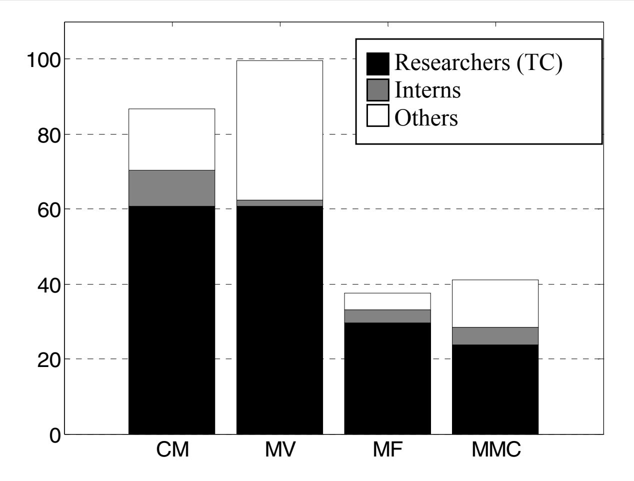

Figure 2. Human resources expressed as the number of persons (full-time [TC] researchers, interns and other support personnel) allocated to this area at the Technical University of Catalonia (UPC), University of Barcelona (UB), University of Gerona (UdG), and University Rovira i Virgili (URV) in the year 2003. The data were classified with respect to CM, MV, MF, and MMC. Data from the UPC's Dept. 737 (Materials and Structures Resistance in Engineering) were divided into the areas MMC and CM according to the percentages mentioned in the text.

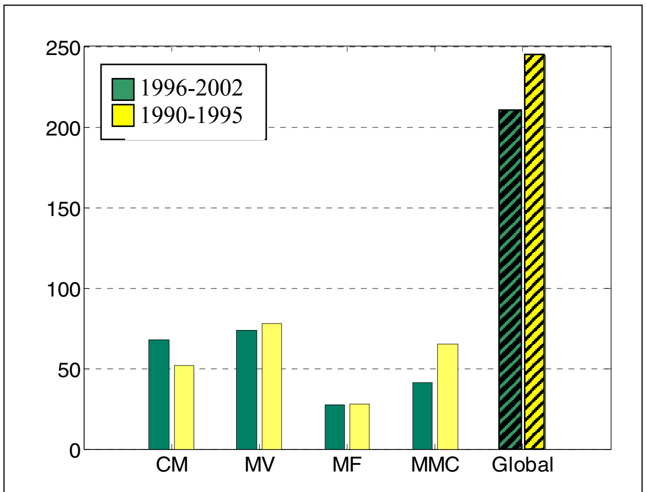

Figure 3. Annual average amount of human resources expressed as the number of person (full-time [TC] and half-time [TP] teaching staff, interns, and others) at the UPC, UB, UdG, and URV. The data were classified with respect to CM, MV, MF, and MMC (see Fig. 1) for the periods 1996-2002 and 1990-1995. Data from the UPC's Dept. 737 (Materials and Structures Resistance in Engineering) for the period 1996-2002 were divided into the areas MMC and CM according to the percentages mentioned in the text.

that the average number of people per area has not changed substantially between the two periods.

Economic Resources

This section includes both public (projects, special actions, aid for consolidated groups, travel grants, etc.) and private (agreements with companies) economic resources. Public resources were distinguished according to their source: autonomic (from the Government of Catalonia), state-supported, European, and others. Complete and reliable information could only be obtained for each department from the UPC. As with human resources, the total resources of Department 737 were adjusted to 76% for the MMC field and to 24% for CM. The results are shown in Fig. 4 (changes between 1996 and 2001 for the all the areas) and Fig. 5 (annual average for the areas during the period of the report) and in Table 5.

The data concerning human and economic resources provides an interesting relative indicator: the average annual total financing, for the evaluated period, per investigator. Figure 6 provides information about this indicator for the different areas of EM-M at the UPC, and compares them with the reference values of Catalonia and Spain provided in the Introduction (Sect. 1).

A comparison between economic resources in the last six years and those during the period covered by the previous report (1990–1995) is shown in Figs. 7 and 8.

Financing during 1996–2002 was greater for all areas except MMC. This exception may be due to the fact that an im-

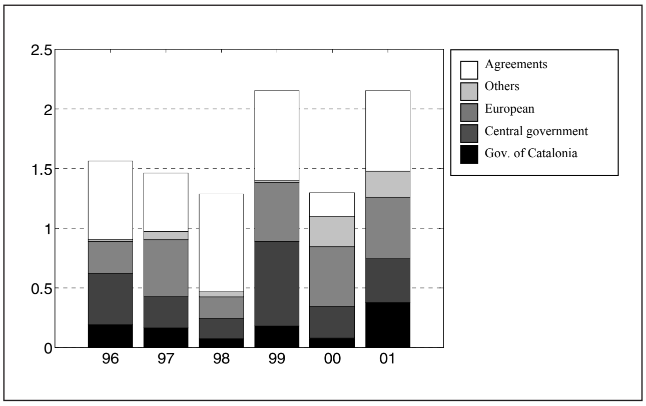

Figure 4. Evolution of economic resources (in millions of Euros) between 1996 and 2001 for all the areas in the field of Mechanical and Materials Engineering at the UPC. The data were classified according to the source of funding. «Others» refers to private sources.

Table 5. Annual average (1996–2001) funding (in thousands of euros) of Mechanical and Materials Engineering at the UPC

	CM	*MV*	*MF*	*MMC*	*Total*
Agreements	0.1391	0.2495	0.1465	0.0640	0.5990
Others	0.0299	0.0010	0.0634	0.0073	0.1016
European	0.2679	0.0089	0.0838	0.0435	0.4041
Central government	0.2237	0.0731	0.0502	0.0232	0.3702
Government of Catalonia	0.0650	0.0666	0.0180	0.0255	0.1750
Total	0.7254	0.3991	0.3619	0.1635	1.6499

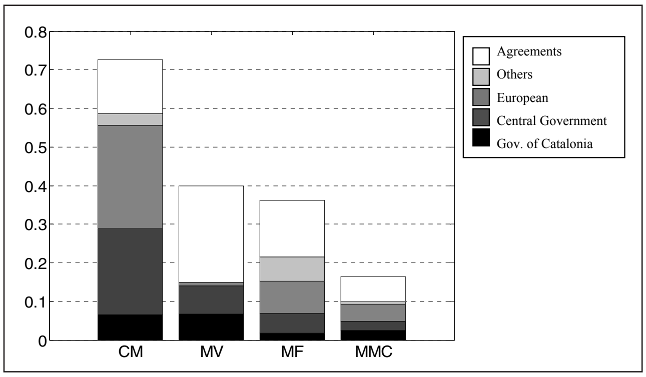

Figure 5. Annual average economic resources (in millions of Euros) at the UPC in the areas CM, MV, MF, and MMC for the period 1996-2001. The data were classified according to area of Engineering and source of funding. «Others» refers to private sources.

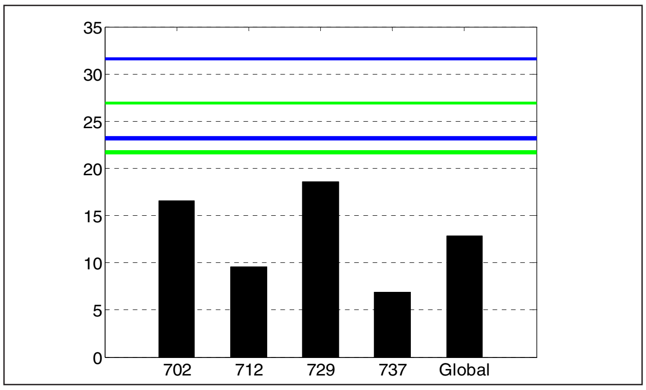

Figure 6. Annual average total (public and private) financing in thousands of Euros, per researcher during the period 1996-2002. Values for CM, MV, MF, and MMC at the UPC and the corresponding global values. The contributions of the Spanish Central Government, Spanish universities, Catalan Government, and Catalan universities were 31.63, 26.9, 23.17, and 21.7 thousand Euros, respectively.

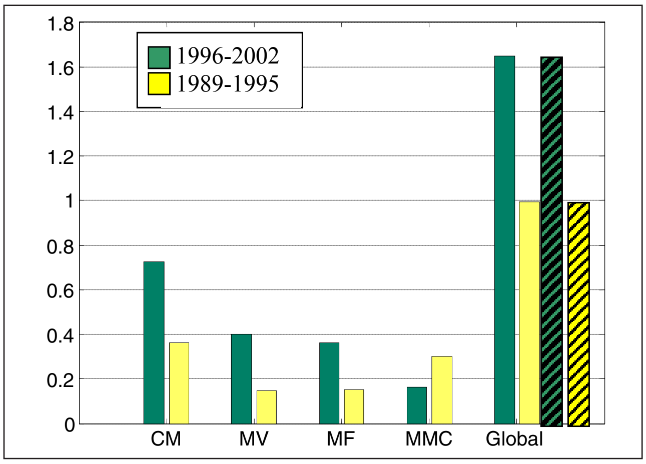

Figure 7. Annual average total (public and private) economic resources (in millions of Euros) for the periods 1996-2001 and 1990-1995 at the UPC for the areas CM, MV, MF, and MMC and the corresponding global values.

portant proportion of MMC income was designated for training activities, which were included as economic resources.

Figure 8 shows the evolution of financing according to the different sources: (a) public autonomic and state financing, (b) European, and (c) private. For all three sources, financing during 1996–2002 was well above that during 1990–1995.

Figure 9 shows the average annual financing per person for both periods. As previously explained, it was not possible to determine the number of investigators for the period 1990–1995; thus, Fig. 9 refers to the total number of persons. As seen in the figure, the improvement in financing for MV and MF over the last 6 years is remarkable.

Results

Doctorate Programs, Doctoral Theses

Active research implies not only output but also training of research staff. In Mechanical Engineering, this aspect is related directly to postgraduate studies. Doctoral programs offered in the four areas (CM, MV, MF, and MMC) and the number of doctoral theses completed are clear and direct indicators of research activity.

A doctorate in Mechanical Engineering (and Industrial Engineering in general) is, in principle, not necessary for people who want to work in the industrial sector (which corresponds to the most people graduating with a degree in engineering). However, it is essential for those working at the university who want to ensure job stability. For this reason, the indicators relative to doctoral training are usually well below those of other scientific fields.

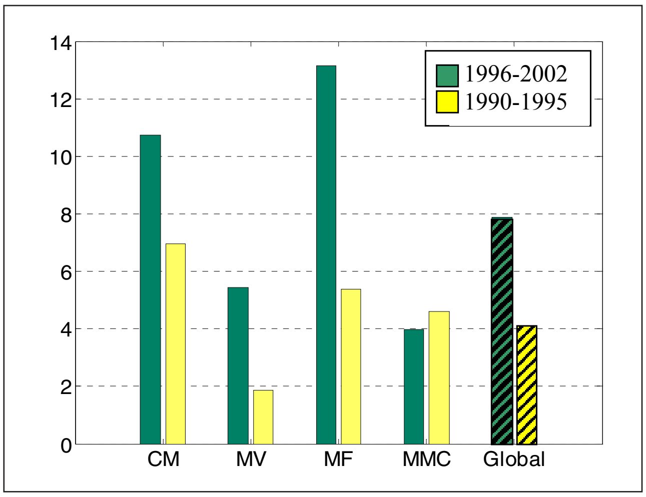

Figure 9. Average annual total (public and private) financing (in thousands of Euros) received per person working at the UPC in the areas CM, MV, MF, and MMC during the periods 1996-2002 and 1990-1995. The corresponding global values are shown for comparison.

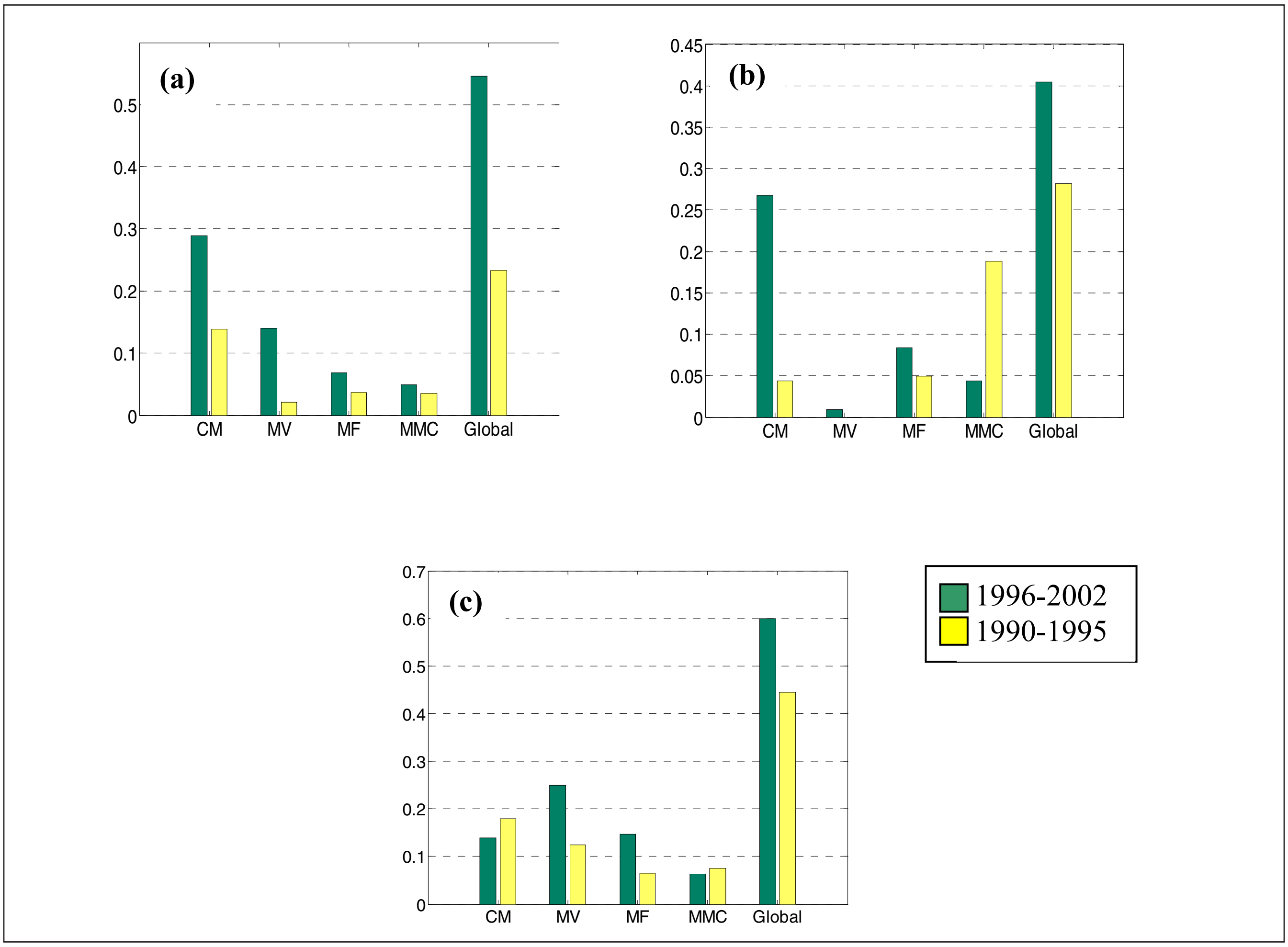

Figure 8a-c. Annual average economic resources (in millions of Euros) at the UPC during the periods 1996-2001 and 1990-1995: autonomous government and state-supported (a), European (b), and deriving from agreements and services (c). The data were classified according to the area of Engineering (CM, MV, MF, MMC).

Table 6. Doctoral programs in Mechanical and Materials Engineering in Catalonia

Program	*Area*	*University*	*Department*
Materials Science and Metallurgic Engineering	CM	UPC	Materials Science and Metallurgic Engineering (702)
Mechanical Engineering	MV	UPC	Mechanical Engineering (712)
Fluid Techniques	MF	UPC	Fluid Mechanics (729)
Structural Analysis	MMC	UPC	Materials and Structure Resistance in Engineering (737)
Technological Innovation Projects in Product and Processes Engineering	MV	UPC	Engineering Projects Mechanical Engineering
	UdG		Mechanical and Industrial Construction Engineering
Materials Technology	CM	UB	Chemical Engineering and Metallurgy Applied Physics and Optics Chemical Physics Inorganic Chemistry Crystallography, Mineralogy, and Mineral Deposits
Instrumental Techniques in Physics and Materials Science	CM	UB	Applied Physics and Optics Fundamental Physics
Graduate Studies in Chemical and Process Engineering (2/20)	CM	URV	Chemical Engineering Mechanical Engineering

Since completing a doctoral thesis demonstrates investigative capacity, it is no surprise that research in EM in the industrial sector has not achieved the desired levels.

All the doctoral programs related, to a greater or lesser extent, to Mechanical and Materials Engineering in Catalan universities are listed in Table 6. Given that some of them are inter-

Table 7. Indicators of post-graduate studies in the field of Mechanical and Materials Engineering at the UPC

Annual averages (theses directed in the departments)	*Dep. 702 CM*	*Dep. 712 MV*	*Dep. 729 MF*	*Dep. 737 MMC*	*Total*
Number of theses per academic year (1996–1997 to 2001–2002)	6.50	1.83	2.50	3.83	14.66
Number of theses per investigator and academic year (1997–1998 to 2000–2001)	0.179	0.044	0.128	0.123	0.114

departmental, training in EM-M does not appear to be very significant. This also applies for Graduate Studies in Chemical and Processes Engineering at the URV, whose content of EM-specific subjects accounts for only 10% of the curriculum. The two Materials programs at the UB are similar to the program at the URV, although they are more related to Materials Science than the former. This is a consequence of Industrial Engineering not being offered as a degree program by either university.

This report considers the first four programs shown in the table, all of which belong to one department at the UPC. These were determined to be the most important programs with respect to training in this field, and the indicators refer exclusively to them.

It should be noted that the Department of Materials Resistance and Structures in Engineering (737), besides including the different EM areas, also contains branches from Civil Engineering, complicating the separation of theses and investigators assigned to each field. Likewise, since many papers refer to MMC (as verified by inspection of the titles of the corresponding theses), it was decided to consider all the theses in this area.

Also, there are two different types of theses associated with each department: (1) theses directed by a professor from the department, and (2) theses presented to the department. Generally, these do not coincide since a thesis presented to a department may have been directed by a professor from outside the department. This report has based used theses directed by professors from the department as the indicator.

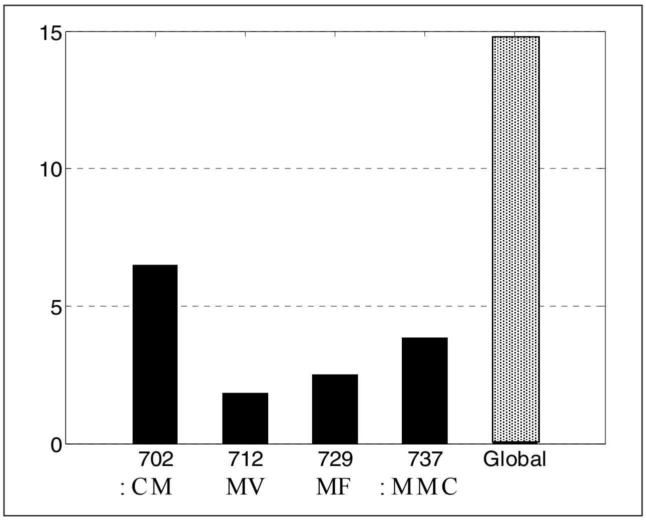

Figure 10. Average number of doctoral theses directed in the UPC departments CM, MV, MF, and MMC per academic year during the period of 1996-97 to 2001-2002. The corresponding global number is shown for comparison.

Table 7 and Figs. 10 and 11 present the average indicators per academic year.

Figure 12 shows the number of theses directed by professors at the UPC as a function of financing, for each of the departments considered and for all departments.

Lines of research and indexed articles

All research results are associated with a line of investigation. Each department has defined a certain number of lines, and an investigator can be involved in more than one.

While the number of lines of research per department is not a priori an indicator of activity, it can provide insight into related scientific output indicators. For example, although a given university department may appear to be very productive, it could

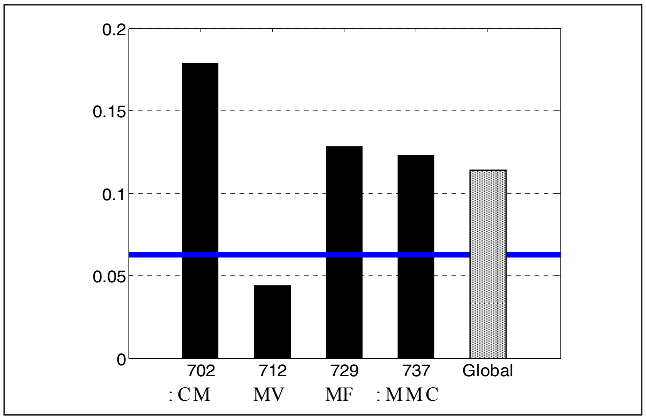

Figure 11. Average number of doctoral theses directed in the UPC departments CM, MV, MF, and MMC per investigator and per academic year during the period 1997-98 to 2000-2001. The average for Catalonia (blue line) was 0.063. The corresponding global number is shown for comparison.

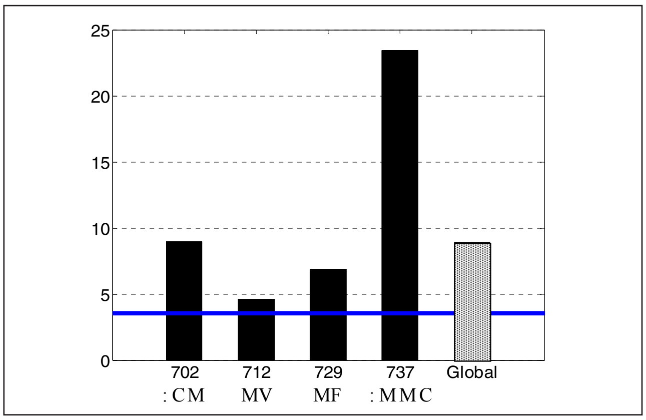

Figure 12. Average number of theses directed in the PC departments CM, MV, MF, and MMC during the period 1997-98 to 2000-2001 per million Euros. The average for Catalonia (blue line) was 3.56. The corresponding global value is shown for comparison.

be that a high percentage of this output corresponds to only one line of research.

Unfortunately, this situation is very frequent. At the UPC, this problem led to a redefinition of lines of investigation and thus to the creation of research groups with a reduced number of lines of research, so that there will be a minimum of five active PDI members, and their research output will have a certain threshold value (yet to be defined). In this restructured situation, one person will only be able to be involved in one line of investigation.

As in other sections, precise information about existing lines of research was only available for the UPC. During 1996–2002, some lines were discontinued while others were initiated. Currently, the active lines of research correspond to a fusion of former ones. In Table 8, previous lines of research that have since been discontinued are noted in italics and the operative ones are listed in normal font. The number of investigators for each line of research corresponds to the period 2003–2004.

There is a broad line of research for all departments (as indicated by the name of the department), and investigators whose research output does not belong to other lines were included in this category. The figures for investigators in this situation are not evaluated easily; thus, they cannot even be assumed to correspond to the total number of investigators in a department minus those involved in specific lines of research, since there are also investigators who do not publish.

Table 8. Research lines and number of investigators in Mechanical and Material Engineering at the UPC: 1996–2002

Department	*Area*	*Research line*	*Number of investigators*
702	CM	Polymer and composite technology	14
	CM	Mechanical behavior of metals and ceramics	10
	CM	Biomechanics and biomaterials	15
	CM	Conformational processes of metallic materials	14
	CM	*(Light alloys)* Light alloys and surface treatments	6
	CM	General line	–
712	MV	Environmental noise pollution	9
	MV	Machines and vibroacoustics theory	8
	MV	*(Musical acoustics)* *(Cinematic analysis and multisolid systems dynamics)* Mechanics and acoustics	2
	MV	Processes of mechanical manufacture	3
	MV	Optimization of design of mechanisms and machine elements	10
	MV	Machine and transmissions design: mechanical simulation and structural analysis	9
	MV	Transport engineering and exploitation	7
	MV	General line	–
729	MF	Systems of materials in fluid state	3
	MF	Oil-hydraulic and pneumatic control and power systems	11
	MF	Turbomachine systems	8
	MF	General line	–
737	MMC	*(Development of numeric models for the solution to Euler Navier-Stokes equations)* *(Finite elements model for fluid flux problems)* *(Analysis of scale models in structures)* Analysis of structures and mechanics of continuous mediums	17
	MMC	*(Structural analysis for the meted of finite elements)* *(Dynamic analysis of structures)* *(Educational software for structure analysis)* *(Problems connected to structural engineering)* *(Numerical models for non-linear analysis of plates and structures)* *(Analysis of structures with compound materials)* Advanced structural analysis through numerical and experimental methods	16
	CM	*(Analysis of metal components)* *(Analysis of structures with compound materials)* Study of resistant elements and manufacturing processes through experimental and simulation techniques	6
	MMC	General line	–

Scientific output is mainly measured through the number of publications in journals of prestige (those included in the Journal Citation Report, JCR). Publications aimed at congresses are not considered representative, since the majority do not undergo the rigorous process of selection by reviewers, and therefore their scientific level (novelty and seriousness of the study and/or obtained results) cannot be guaranteed. When papers at a congress correspond to high-quality scientific work, they usually have been or will be published in JCR journals.

Another indicator that was rejected in this study was publications in books. Almost all publications that appear in the résumés or web pages of a research group tended to be Abstracts and papers included in the record of congresses or were books having a pedagogic purpose.

Table 9 and Fig. 13 indicate the total number of articles for all Catalan universities for the years 1996–2002. In both, articles from Department 737 of the UPC were subdivided by area.

Table 9. Annual average of indexed articles corresponding during the period 1996–2002 in Mechanical and Materials Engineering

	CM	*MV*	*MF*	*MMC*
UB, UdG, URV	15.7	0	1.7	0
UPC	42.7	3.17	1	13.7
Total	58.4	3.17	2.7	13.7

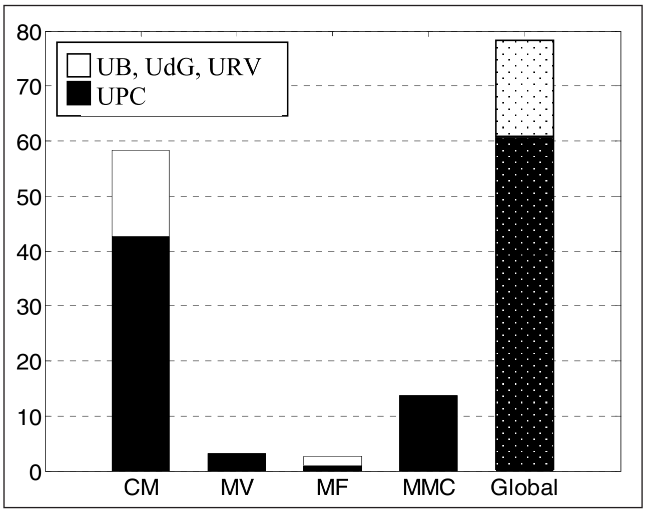

Figure 13. Annual average number of indexed articles in the four areas of EM-M (CM, MV, MF, MMC) in the period 1996-2002 for all Catalan universities. The corresponding global number is shown for comparison.

Absolute indicators are poor representatives of scientific output since they do not take into account the human resources of each group. For this reason, it the indicators have also been reported relative to each investigator. As mentioned in above, since there are research groups whose activity is not exclusively in a single area, and since a single investigator can work in several areas, the indicators should be taken as a qualitative orientation. Figure 14 provides the same information as Fig. 9, but per investigator.

Finally, and exclusively for UPC departments, it was possible to classify output per departmental research line. This information confirmed that the number of research lines per department is not an indicator of activity a priori. Table 10 and Fig. 15 list the number of articles per investigator for each line of research of the four departments.

Another interesting relative indicator is that relating the publication of articles with funding. This information for the UPC departments is shown in Fig. 16.

A comparison of the indexed articles published in 1996–2002 vs. 1990–1995 is shown in Figs. 17 and 18. There was an important increase in production in the areas of CM and MMC, a smaller increase for MF, and a decrease for MV.

General considerations and conclusions

Analysis of the EM-M data presented in the previous sections makes clear that, even though they are included in the same field, Materials Engineering (which includes all areas of CM) and Mechanical Engineering (which includes the other three areas, MV, MF and MMC) show very different behavior. While the indicators describing Materials Engineering are, in most cases, above the average of those for Catalonia and Spain, those which refer to MV and MF are well below. The MMC situation is intermediate. This difference in behavior is not due to the differences in size of the research groups in each area, since the number of CM investigators is comparable to that of MV (an average of 43.81 investigators for CM and 41.67 for MV).

The conclusion that can be drawn from this is that if all PDIs working full time are considered to be investigators, only a small percentage of them seem to actually carry out this function in the MV area. The causes can be diverse, such as the fact that some PDIs are employed in technical and not higher-level colleges. Thus, while all of investigators in CM belong either to the Faculty of Chemistry of the UB or to the School of Engineering of Barcelona (ETSEIB) of the UPC, MV investigators are spread out in similar proportions in three higher-level centers (ETSEIB, ETSEIB in Terrassa, and the UdG) and four technical universities: (School of Technical Industrial Engineering of Barcelona (EUETIB), the EUETIT in Terrassa, the Technical School of Vilanova i la Geltrú (EUPVG), and the EUPM in Manresa. Technical centers do not have the research tradition

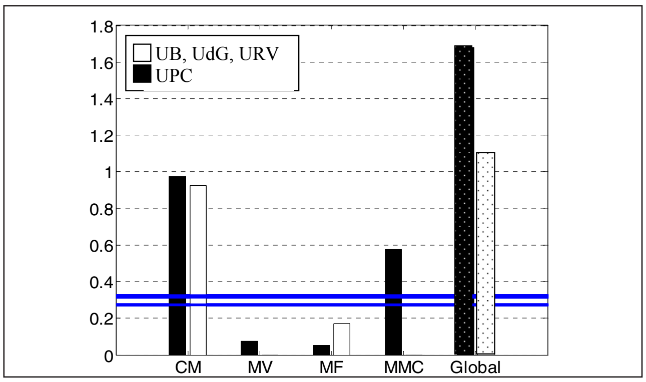

Figure 14. Annual average number of indexed articles per investigator in the four areas of EM-M (CM, MV, MF, MMC) for all Catalan universities in the period 1996-2002. The global value is shown for comparison. The numbers for Catalonia and Spain (blue lines) were 0.318 and 0.274, respectively.

Table 10. Research lines and annual average number of JRC articles in Mechanical and Materials Engineering at the UPC: academic years 1996–1997 to 2001–2002

Department		*Research line*	*Articles per year and investigator*
702	1	Polymer and composite technology	0.57
	2	Mechanical behavior of metals and ceramics	0.72
	3	Biomechanics and biomaterials	1.07
	4	Conformation processes of metallic materials	0.29
	5	Light alloys and surface treatments	0.11
712	1	Environmental noise pollution	0.04
	2	Machines and vibroacoustics theory	0.04
	3	Mechanics and acoustics	0.92
	4	Processes of mechanical manufacture	0.17
	5	Optimization of design of mechanisms and machine elements	0
	6	Machine and transmission design: mechanical simulation and structural analysis	0
	7	Transport engineering and exploitation	0
729	1	Systems of materials in fluid state	0.06
	2	Oil-hydraulic and pneumatic control and power systems	0
	3	Turbomachine systems	0.08
737	1	Analysis of structures and mechanics of continuous mediums	0.34
	2	Advanced numerical analysis through numerical and experimental methods	0.33
	3	Study of resistant elements and manufacturing processes through experimental and simulation techniques	0.72

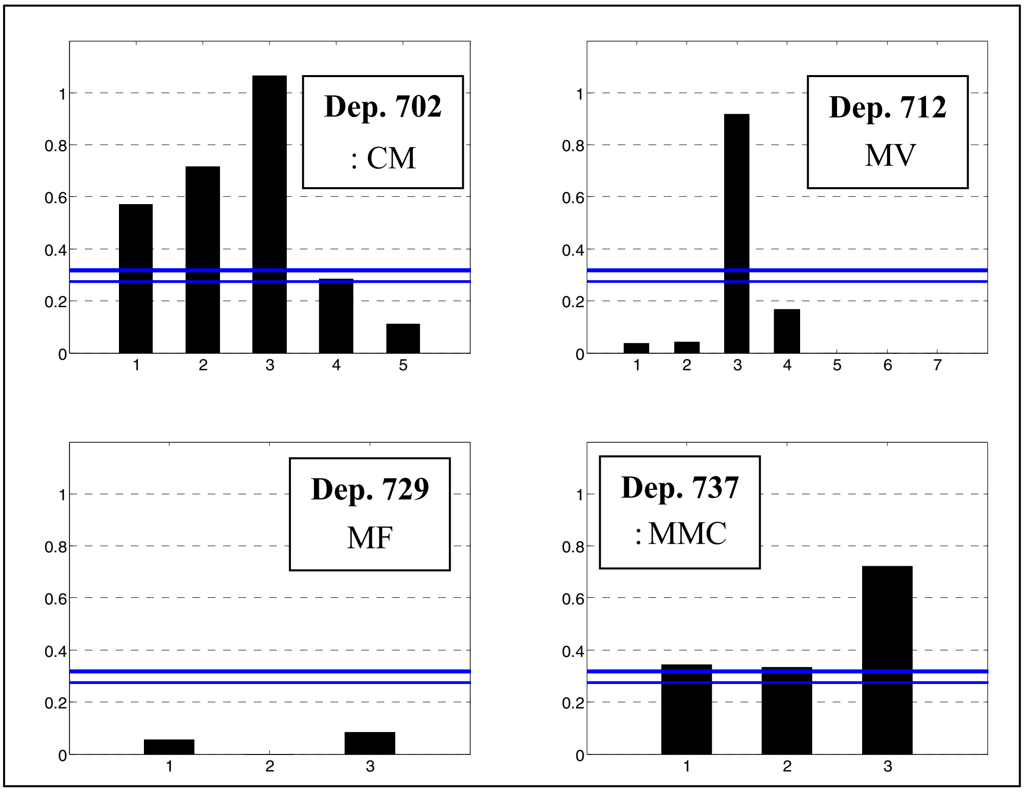

Figure 15. Annual average number of indexed articles per investigator for each of the lines of research (x-axis) pursued in the departments CM, MV, MF, and MMC at the UPC during the period 1996-2002. The numbers for Catalonia and Spain (blue lines) were 0.318 and 0.274, respectively.

of higher-level centers, and although there are PDI working TC, their link to active research is less intense (except for those who belong to the CDAL of the EUPVG, but in this case the personnel is in the Materials field).

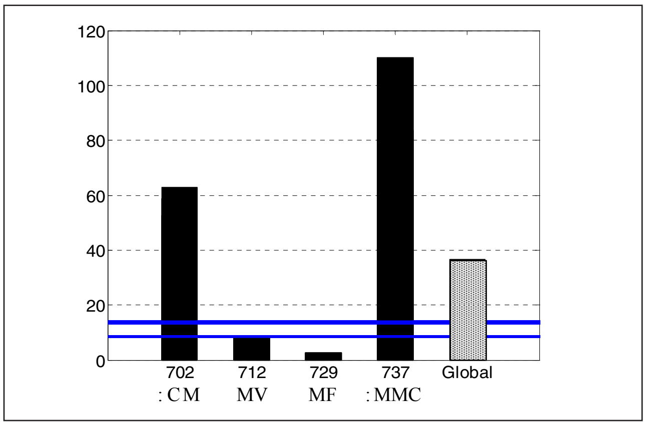

Figure 16. Annual average number of indexed articles per million Euros in the four areas of EM-M at the UPC during the period 1996-2002. The global value is shown for comparison. The numbers for Catalonia and Spain were 13.75 and 8.66, respectively.

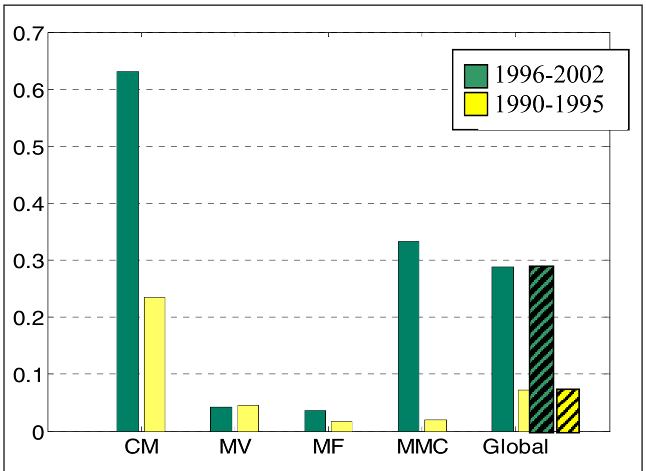

Figure 17. Annual average number of indexed articles per person (full-time and half-time teaching staff, interns and others) in the areas CM, MV, MF, and MMC for all Catalan universities during the periods 1996-2002 and 1990-1995.

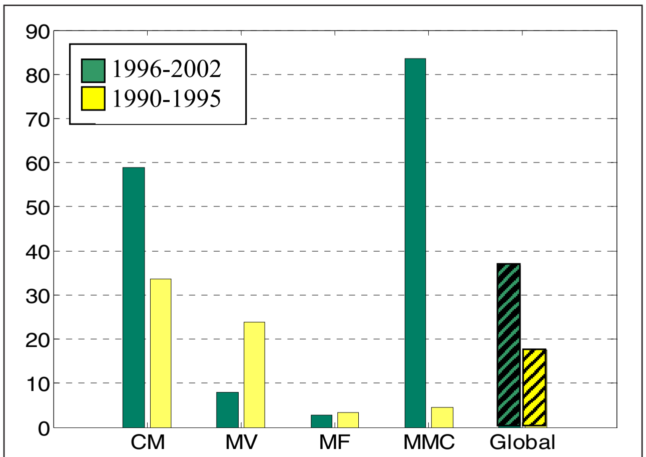

Figure 18. Number of indexed articles per million Euros in the UPC's departments of CM, MV, MF, and MMC during the periods 1996-2002 and 1990-1995. The global value is shown for comparison.

Productivity in the area of MF is low, but this field is also smaller than the other two. Curiously enough, the most active section is at the URV, even though it is a university with a shorter history than the UPC.

Another justification for the differences in scientific production levels between CM and the other areas is found in the economic resources. CM has at its disposal much higher average funding than the other areas. The area with most resources after CM is MV, and its resources are 1.8 times less. Nonetheless, this does not imply that its scientific output is also 1.8 times less (as evaluated by the number of indexed articles). In reality, MV output does not even add up to 1% of that of CM.

A surprising fact is the low level of financing received by the MMC area. Although funding is 4.5 times below that of CM, it ranks second in the production of scientific articles. This leads to the conclusion that an important part of MMC's economic resources (which correspond exclusively to Department 737 at the UPC) comes from sources that were not included in the economic indicators analyzed in this report, i.e., income associated with continuous training (postgraduate studies, master degrees, etc.) An important proportion of the PDIs of Department 737 are also affiliated with the CIMNE, whose main activity is training, with a correspondingly large income.

A more detailed study of the source of economic resources shows that, in MV, a high percentage (with respect to the total value) of resources is associated with agreements. The logical conclusion is that the output of a large number of MV PDIs arises exclusively from contracts with the business world. The exact nature of the scientific production is unclear, and can range from projects or services typical of a technical office to research activities promoted in the industrial world. While the absence of publications regarding this type of activity is problematic, since the organization responsible for accrediting research projects within companies (the AIDIT) is still under a trial period, the agreements with the business sector may well be research-related but protected under confidentiality clauses.

Activity linked to agreements with the private sector has incentives that, in principle, are lacking in pure research activity, and which effectively increases the income of PDIs involved in this type of work (in accordance to the restrictions planned by the law). Also, given that the economic resources coming from the public sector are usually insufficient for both the acquisition of infrastructure and the development of research activities, agreements with private companies could help to finance research. It is logical, therefore, that universities have an interest in promoting this component. The problem is that there is no minimum research requirement associated with these activities. The business world also has an interest in promoting its R+D activities in collaboration with universities, due to the fiscal and economic advantages implied.

Moreover, the advantages of collaborating with industry are not purely economic: important research projects can be developed with these agreements, which is why Technology Transfer Centers (CTT) from the different universities should encourage them. Often enough though, CTTs end up functioning as lawyers, with little knowledge of the scientific and technological level of the agreements they negotiate, or about adequately linking universities and businesses.

The solution to this vicious cycle regarding agreements with the private sector is to be found in various actions. First, CCTs must act as promoters of university research activity and not only as income solicitors. Nonetheless, since this cannot guarantee the formation of university-business collaborations; the process of accreditation plays an important role. Therefore, second, the AIDIT should function in a stable manner as the key institution in charge of certifying the level of projects. CTTs and AIDIT should work in tandem to guarantee the quality of R+D activities resulting from collaborations between the universities and the private sector.

Actions taken by CTTs and the AIDIT may still be insufficient if there is no competent research staff. Investigative competence is, in principle, guaranteed by obtaining a doctorate degree. However, while within the university, a doctorate is necessary for labor stability and promotion, in the business world it does not posses the same value nor does it guarantee career advancement. Thus, promoting the prestige of a doctorate in the business field would positively affect the scientific level of companies' R+D activities.

In general, it is evident that universities lack mechanisms to control the research output of PDIs, and there are no clear incentives to promote research. The law clearly states that PDIs have research obligations, but it does not define the corresponding indicators necessary to evaluate it. For this reason, it is impossible to demonstrate the inactivity of PDI in a given field.

Activity, however, can be demonstrated through publications. According to the Central Government, any PDI should complete a minimum annual scientific production of 0.5 indexed articles per year in a period of six years. However, this minimum does not improve the conditions for research. A more effective incentive would be to relieve part of a PDI's teaching responsibilities or to provide a sabbatical to any person whose output was clearly below this minimum. This, together with greater access to interns and support personnel would offer measures that would increase the production and the quality of research.

Electrical and Energy Engineering

Research and technological development in the energy field

"*High quality research is more and more complex, interdisciplinary and expensive, and at the same time demands a 'critical mass' of people which is constantly increasing. There are very few research teams, laboratories or companies than can claim in a reasonable way that they are capable of responding to these challenges. Even countries as a whole are constantly finding it more difficult to work and develop a leading role in many fields of scientific and technological progress*."

Alejandro Zunita, Euratom-European Commission

Characteristics of the field

The biosphere consists of two so-called primary energy sources: (1) a continuous presence of potential energy originating in the permanent action of three natural sources of energy: solar, geothermic, and gravitational, and (2) a non-renewable, finite deposit of chemical (fossil) and nuclear (uranium, deuterium) energies. There are multiple processes of conversion between these forms of energy: chemical, nuclear, thermal, electromagnetic, electrical, and mechanical (work, kinetic, and potential). These processes have resulted in multiple strategies that allow humanity to use the different forms of primary energies for their benefit: heating and cooling (industrial, agricultural, alimentary, and domestic uses), mechanical energy (transport, domestic and industrial equipment), and radiation (illumination, telecommunications).

The search for primary energy resources is the domain of the sciences, particularly geology, physics, biology, mining, and agronomy. Industrial Engineering has traditionally been in charge of the development of most of the conversion, transport, and energy-use processes. These constantly developing processes involve investigations based in multiple areas of knowledge.

In addition, the massive use of primary energies has generated new areas of investigation, with new scientific and technological approaches, into the conversion, transport, and application of energy so that its use becomes more efficient and environmentally friendly, and a policy of sustainable development can be implemented thereby avoiding the destruction and depletion of natural resources. These considerations also generate new areas of research and development, not only in Industrial Engineering, but in many of the basic and technological sciences.

In 1999, the Institute for Catalan Studies sponsored the 'Reports of Research in Catalonia. Industrial Engineering', which covered the years 1990–1995 period for the same fields as the present report. Most of the difficulties manifested in preparing that report have reappeared, and in some cases worsened, in this update. In the field of Industrial Engineering (energy), are difficulties due to the wide variety of areas and the large number of departments (in different centers, schools, and faculties) that are in some way involved in the various lines of Industrial Engineering research.

For this revision of the state of research in the field of energy, the energy plan set forth by the Government of Catalonia through the Department of Industry, Commerce and Tourism ("Plan for energy in Catalonia on the horizon of the year 2010", published in the year 2002) is of interest. That plan led to the establishment of the "Program for research and technological development promotion for the energy field", which considered R+D in Catalonia. Among the studies used by the Department of Industry, those done by the Catalan Institute of Energy (ICAEN), i.e., the 1991 Study of Energy-Related R+D in Catalonia, and the 1998 Study of R+D for Energy and Electric Engineering stand out. Both studies emphasized the "*contributions to knowledge of reality, possibilities and aspirations of the forces implied in the research and energy development processes in Catalonia*".

The current situation for research and development in the energy sector is related to the general situation of research and technological development in Spain. The frame of reference is the European Union, which acts as a source of convergence and as a source of financing.

The field of technological and energy engineering

Energy constitutes a topic area in the new "National plan of scientific investigation, development and technological innovation 2004–2007". Most of the focus is on engineering and technology, although other disciplines, such as agricultural science, are also considered.

Energy availability greatly influences development and economic activity, and it is a decisive component of sustainable development and environmental conservation, which is why it is of strategic and societal importance.

Given the multiple scientific and technological bases that promote R+D in energy engineering and its wide application, all sectors of society are affected by events in this area: civil service, higher education, business, and private non-profit institutions (IFSFL), as well as many areas of sciences and engineering. Except in state-supported research centers –Research Center for Energy, Environment and Technology (CIEMAT), the National Renewable Energies Center (CENER), CSN and ENRESA in nuclear energy– and in large companies of the energy sector, this diversification has led to the dispersion of research groups, and thus the creation of small and medium-size groups characterized by a low level of productivity.

a) Perspectives from the Autonomous Government of Catalonia

Perspectives for R+D in energy for Catalonia is presented in the "Plan for energy in Catalonia on the horizon of the year 2010". Besides confirming the gulf between research and technological research in Catalonia and Spain and in more developed countries, the report points out the factors which have led to this low level of activity: *the main specific factors that have created the low activity hitherto are the following:*

- *Low industrial demand for R+D*
- *Lack of resources and specific incentives from the central government*
- *Low productivity of R+D structures*

The low industrial demand for energy R+D in Catalonia is fundamentally due to the characteristics of the Catalan industrial sector, which possesses few important indigenous firms.

Regarding the lack of resources and specific incentives from the Central Government, the low presence of energy technology in state R+D programs must be emphasized. Since the beginning of the 1980s and until 1995, research and energy development were placed within the context of the "Energy Investigation Plan" (PIE), which included, besides the typical administrative functions, an R+D financing mechanism based on funds deriving from energy tariffs. With the subsequent transformation of the energy sector, due to deregulation and subsequent liberation of the sector, the PIE disappeared. The elimination of financing from from energy-related resources has been progressive for all energy sectors: electric, carbon-based, and natural gas. Instead, at present, only research in renewable energies and the environment receives fiscal aid through taxes. Thus, most research is aimed at these areas.

It was not until 1999 that an initiative was established in the sector, through the "Energy I+D Technological Program" (TEIDE) in the "Technology, Safety and Industrial Quality Support Initiative" (ATYCA) framework. The program included the "Energy Sector" of the "National plan of scientific investigation, development and technological innovation 2002–2003" and now incorporates the new "National plan of scientific investigation, development and technological investigation 2004–2007".

As previously mentioned, in the last few years, the most important R+D-specific government resources have been des-

Table 11. R+D in the energy sector and projects developed in Catalonia

Research sector	*Lines of research*
Electrical energy	Modeling, machines and electric automobile project; electric power systems; electric motors; optimization and simulation of network fluxes; illumination; measurement and control of electric magnitudes; sensor technology; superconductivity
Nuclear energy	Safety in the facilities; detection of radioisotopes; use and risks of radiations; nuclear fusion
Natural gas	Applications of natural gas
Renewable energies	Renewable energy resources; aerogenerators; photovoltaic solar energy (application in cars, architectonic applications, cells, photovoltaic illumination); thermal solar energy (air conditioning, seawater desalinization); biomass and residues
Energy systems	Energetic efficiency; cogeneration and combined cycles; turbomachine systems
Heat and mass transference	Modeling and simulation; thermal design and modeling of industrial equipment and components
Acclimatization	Bioclimatic architecture; transparent insulators; compressor design; adjustable heat transmitters; packing of thermal energy; new air-distribution techniques; heat recuperation for housing; thermoclays; conditioning systems; cooling (indirect evaporator, desiccation, absorption)
Transport	Design of more efficient cars; ignition and combustion in engines; energetically efficient systems; improvements in internal combustion engines
Information technology and telecommunications applied to energy	Cold machines control through fuzzy logics; advanced telemanagement services; climate control units with EIB or LON bus

Source:Energy plan for Catalonia on the horizon of the year 2010. Government of Catalonia. Department of Industry, Commerce and Tourism. 2002 tined to large research centers, most of which belong to CIEMAT, which does not have a center in Catalonia. The Spanish National Research Council (CSIC) has the Materials Science Institute of Barcelona (ICMAB), which develops lines of research in the field of superconductor materials.

The study sponsored by the Government of Catalonia also highlights the low-level productivity in general of R+D structures, which it attributes to the following factors: "*fragmentation of working teams, the loss of contact of researchers with the market and technological reality, on top of a lack of business structure and orientation, and value given to productive results*."

b) Lines of research and technological development for the energy field in Catalonia, in the technology and engineering framework

Despite the difficult situation described in the previous section, the Government of Catalonia's study highlights an appreciable group of research lines and R+D projects in the energy field. Table 11 shows the main sectors of R+D and their lines of research.

Fundamentally, research is produced in universities and institutional research centers. The study of the Government of Catalonia shows that, with few exceptions, companies that produce energy equipment have a much lower volume of R+D. The flow of investigation commissioned by energy companies to universities and investigation centers has also decreased since the disappearance of the PIE.

Nonetheless, the financial participation of the energy business sector is more active than that of the other sectors (universities and public administration) regarding European and state energy R+D. The contribution of the Fifth EU Framework Program is not significant, in that Spain's share was 6.1% The Euratom Framework Program for nuclear energy has a similar prospect, since despite there being Spanish participation in half the projects, the of the share of funding is 6.8%

Tables 12 and 15 summarize Spanish and Catalan participation in the fifth Framework Program (VPM).

The participation of companies dedicated to technological development and innovation in the non-nuclear energy sector should be highlighted, since in Spain as a whole and for all of the programs it is 54%, whereas in Catalonia accounts for 82.9% of the participation.

Current proposals for technological investigation in the energy field

New proposals for research in the energy field are found in both the "National investigation plan 2004–2007" of the Ministry of Science and Technology, and the "III plan of research in Catalonia 2001–2004" from the Department of Universities, Research,

Table 12. Framework Programs (PM) for the funding of R+D in the European Union

Period	*1987-1990 (II)*	*1990-1994 (III)*	*1994-1998 (IV)*	*1998-2002 (V)*
Budget for the PM (millions of Euros)	5396	8409.20	12 530.40	14 960.00
Spanish contribution to the budget of the EU (%)	7.4	8.4	6.5	7.3
Spanish return in the PMs (%)	5.5	6.3	6.3	6.1

Table 13. Spain's participation in the VPM (per sectors

	Millions of Euros	*Total return (%)*	*Percent of groups*
Businesses	492.3	54	38
University	219.0	24	28
Research centers	155.1	17	23
Others	45.6	5	11
Total	912.0	100	100

Table 14. Spanish and Catalan participation in the V Framework Program (per specific program)

Specific program	*Spanish participation (in millions of Euro)s*	*Catalan participation (in millions of Euros)*	*Catalan participation (%)*
Information technology Industrial technologies Environment Life sciences International cooperation Innovation Training and mobility	838.1	90.15	10.8
Energy (excluding nuclear energy)	73.9	9.26	12.5
Total	912.6	99.41	10.9

Table 16. Catalan participation in the energy program (excluding nuclear energy) of the VPM (per execution sector)

Execution sector	*Millions of Euros*	*Percent*	*Groups*
Civil service	0.65	7.0	12
Higher education	0.56	6.1	5
UPC	0.23	2.5	1
UdG	0.25	2.7	2
UB	0.03	0.3	1
URV	0.09	1.0	
Businesses	7.8	84.2	38
IPSFL	0.25	2.7	1
Total	9.26	100.0	56

Source: IEC

and Information Society. More specific to industrial activity is the "Research and technological promotion program" for the energy field, which appears in the "Energy plan for Catalonia on the horizon of the year 2010", published in 2002. The following sections contain a brief commentary on these proposals.

a) National program for energy from the "National plan for scientific investigation, development and innovation 2004–2007"

The "National plan for scientific investigation, development and innovation 2004–2007" is divided into different topic areas and is made up of national plans, including the "National plan for energy". This plan recognizes the strategic importance of the energy field in the various economic sectors, and its essential role as a service for citizens. Furthermore, it establishes that the approach from a scientific and technological perspective must be carried out in a way that favors the achievement of sustainable development, and that through it the larger goals of economic growth and the well-being of the population are met without destroying natural resources.

In particular, the "National energy plan" addresses the R+D+I program in the following terms:

It is necessary to approach R+D+I in those fields in which there is a determined national capacity for investigation and development, an evolution that adapts to national policies in order to promote to the country's maximum technological capacity. For this reason, the energy field will consist of a "National energy plan", divided in two thematic priorities, and a "Thermonuclear fusion subprogram" with the following objectives:

- *The development of forms and conventional uses of energy that are more efficient and environmentally acceptable*
- *The promotion of renewable energies and emerging technologies that provide a safe and efficient energy supply, with performance criteria, through the diversification of sources and geographical origin*
- *Contribution to investigation and development of nuclear fusion promoted by the European Union*

The program takes into account scientific, technological, sectorial, and public-interest criteria. The structure and objectives of the program are summarized in Table 16.

The development of the "National energy plan" is supported by medium– and large-sized centers and installations: CIEMAT (which possesses two large centers, the National Fusion Laboratory and the Solar Platform in Almeria, and multiple medium– and small-sized centers) and CENER. Nonetheless, there should be active coordination between administrations, public investigation organisms, centers and installations, including companies and universities, in order to facilitate the dynamic availability of information. Finally, there are parallel interventions associated with the program that should be engaged in the following topics: human resources, support to business competitiveness, international cooperation, and the promotion of scientific and technical culture.

One of the merits of these programs is the proposal of two thematic priorities and the implicit recognition of the importance of both research in the energy field, which currently supports its conventional use, and the promotion of renewable energies and emerging technologies.

b) Research and technological development promotion in the energy field

The Government of Catalonia, through the Department of Industry, Commerce, and Tourism, elaborated the "Plan for energy in Catalonia on the horizon of the year 2010", which was published in 2002. This plan establishes a program to promote research and technological development in the energy field.

The program assumes that *the research and development of energy techniques is an activity that, despite being entirely included in the field of productive economy, requires the active participation of the public administration in order to be applied*. The reasons behind this proposal include the underdevelopment of these areas in Catalonia and Spain, and the lack of financial contributions to research from the private sector.

Furthermore, without a *productive teams' business schemes or a demand for innovation, R+D activity will not establish itself. Therefore, any intervention in promotion has to provide an integral approach of reinforcing the supply and demand for R+D: increase in the productive scheme of energy equipment goods, incorporation of research and development with strategic elements, promotion of universities and R+D centers, training, and incentives for indigenous innovative technology incorporation*.

Table 16. Structure and objectives of the "National energy plan" 2004–2007

Topic priorities	*Areas of action*	*Specific actions*
Optimization of forms and conventional uses of energy	Improvement of transport fuels	New processes and fuels compatible with current infrastructures
	Technologies for the clean use of carbon and oil products	Development of integrated gasification combined cycle (GICC) and emissions control
	Nuclear fission	Area of nuclear safety and radiological protection and radioactive residues management. Actions of CSN, ENRESA, and the electricity sector
	Polygeneration	Cogeneration, fuel mixtures
	Efficient final energy use	Calorimetric bombs, bioclimatic systems, cold and heat production
	Energy transport	Electric sector: superconductor devises, electrical systems operation help models
	Distributed combustion/active distribution	Electric sector: energy storage systems; large-scale integration of advanced mini– and microsystems of distributed electricity generation.
Promotion of renewable energies and emerging technologies	Evaluation and prediction of renewable energy resources	Databases; advanced technologies of resource use
	Wind power	Creation of infrastructure for the development of aerogenerators; integration of electrical systems; energy storage with a hydrogen vector; environmental integration; maintenance and forecasting techniques and equipment; new transport, assembly and maintenance systems; new developments
	Solar energy	Solar photovoltaic (materials, cells, modules, systems, network coupling); high-temperature solar thermics (linear focus concentration technology; central receptor technology); low– and medium-temperature solar thermics; passive solar energy (bioclimatic systems)
	Biomass	Investigation and development of energy cultivation; solid biofuels; biogas; liquid biofuels
	Other renewable energies	Mini-hydraulics, geothermics, marines
	Hydrogen	Production, production methods without CO_2 emissions; storage; final distribution and supply; rules, specifications and standardization regarding equipment, product quality and safety; evaluate infrastructure and safety equipment
	Fuel batteries	Development of materials for high– and low-temperature batteries; new fuels; systems of application and development of computing methods
Sub-program of thermonuclear fusion	Exploitation of plasma TJ-II installation and physics	
	Development of technologies and materials for fusion installations	
	Promotion of participation in European fusion projects	

Source: "National plan of scientific research, development, and innovation 2004–2007". Volume 1: Objectives and structure; Volume II: Topic areas. Ministry of Science and Technology. November 2003

The program is proposed in the area of energy technology, and action in the scientific field research, autonomous, state-sponsored, and European. The objective of the program is to: *give rise to an intervention directed towards obtaining direct results of productive and transferable technology, since the underdevelopment and the deficits are significant, besides being a decisive strategic field for economic productivity in more developed countries. In this way, the energy R+D Program covers product research and development as well as services in the energy field*.

The specific action of the program is centered on emerging technologies that *contribute to an improvement in energy saving and efficiency, and the use of renewable energies, such as combustion (fuel batteries), vehicle and merchandising transport (electric vehicles, transport organization and control), energy transport (superconductors), solar and wind energy*.

Thus, the program fits in with one of the two theme priorities of the "National energy plan" of the "National plan of scientific investigation, development and innovation 2004–2007", regarding the promotion of renewable energies and emerging technologies that allow for a secure and efficient energy supply, with return criteria comprising the diversification of sources and geographic origin.

Finally, the "Research and technological development promotion program in the energy field" establishes lines of intervention (economic, commercial. and structural; Table 17) and positions the ICAEN as the coordinator and driving force of the R+D innovation program. This is the rationale behind the proposal of the creation of a Program Solicitor's Office, which provides the functions of support, assessment, and promotion of technological R+D in the energy field, as described in Table 18.

The Office is charged with pursuing the establishment of a connection between university research groups, investigation centers, and companies in the energy field with sources of financing and the energy technology market.

The establishment of the Program Solicitor's Office awaits political approval. It is evident though, that an impulse from sectors in the industrial area of the Government of Catalonia is needed.

Table 17. Lines of action in the program to promote from the R+D in the energy field, as contained in the "Energy plan for Catalonia on the horizon of the year 2010"

Lines of action	*Main actions*
Economic	Use of the financial resources outlined in the "Innovation plan for Catalonia"
	Lines of aid to give incentive to the creation of spin-off companies
	Assistance when searching for financing from the Spanish Government and the European Union
Commercial	Commercial promotion
	Public purchase
Structural	Creation of databases, registers, and catalogues (R+D markets: demand; other relevant entities)
	Growth of microbusinesses (actions on demand)
	Creation of research and development support networks to: – Promote businesses and service workshops for energy R+D – Strengthen the use of infrastructure already existent in Catalonia (CERC, LGAI, IDIADA), in Spain (CIEMAT) and the EU – Promote the possible setting up in Catalonia of a center dedicated to energy studies, in collaboration with CIEMAT
	Stimulate actions for the establishment of research groups and departments in Catalonia
	Connection between investigators and development
	Externalize administration and commercial services (creation of a support structure)
	Assessment of technique studies

Source: "Energy plan for Catalonia on the horizon of the year 2010". Government of Catalonia. Department of Industry, Commerce and Tourism. 2002

Table 18. Functions of the Program Solicitor's Office recommended in the «Energy research and development program"

Functions	*Description*
Economic	Support research with its own capital and financing ("Innovation plan for Catalonia") and from external sources (Spanish Government and European Union)
Commercial	Support the marketing of technology and the development of direct commercial actions.
	Collaboration with the Consortium for the Commercial Promotion of Catalonia (COPCA) to prepare international distribution of energy R+D projects and services carried out in Catalonia
	Promotion of the creation of companies or sections of companies from international energy-technology transfer
	Negotiations to include R+D evaluation clauses in public purchases
Structural	Creation, maintenance, and circulation of energy R+D registers
	Assessment of the technological aspects (feasibility, state of the art, and degree of innovation, improvement proposals) and market evaluation (economic and business viability, opportunity, attainable market quotas, improvement proposals) of research projects.
	Organization of meetings
	Continuous (internet) and periodic (journals) scientific disclosure of research projects through own and external means
	Creation and maintenance of a web page
	Organization of congresses and conferences
	Administration support to research groups

Source: "Energy plan for Catalonia on the horizon of the year 2010". Government of Catalonia. Department of Industry, Commerce, and Tourism. 2002

Information sources

For the R+D study of the energy and electricity area, several sources of information were consulted, amongst which, those provided by the Institute for Catalan Studies and the official state and autonomous organizations are highlighted. Information concerning R+D in the energy-industry area of the Administration in Catalonia (General Management of Energy, Catalan Institute of Energy of the Department of Labor and Industry) is of special relevance.

Detailed data about research and technological development in the energy field in the profession of Industrial Engineering were obtained from official sources of the centers.

The sources of reference information that provided data of interest for the report, are as follows:

[1] Statistics Yearbook of Catalonia 2003. Government of Catalonia. Statistical Institute of Catalonia (IDESCAT). Barcelona, October 2003

[2] Statistics of Scientific Investigation and Technological Development (I+D) activities. National Statistical Institute (INE). Madrid 2003

[3] Ministry of Science and Technology. Indicators of Science and Technology. Spain 2002. March 2003

[4] "Energy plan for Catalonia on the horizon of the year 2010". Government of Catalonia. Department of Industry, Commerce and Tourism. 2002

[5] "National plan of scientific investigation, development and technological innovation 2004–2007". Volume I: Objectives and structure. Volume II: Theme areas. Interministry Commission for Science and Technology. 7/11/2003

[6] Catalan Institute of Energy. Department of Labor and Industry. Government of Catalonia

[7] Analysis and planning service of the General Management of Energy, Mines, and Industrial Safety of the Department of Labor and Industry.

[8] Institute for Catalan Studies. Specific information from the databases of the Technical University of Catalonia, University of Barcelona, University of Gerona, Rovira i Virgili University, and Autonomous University of Barcelona.

[9] Technology Transfer Center of the Technical University of Catalonia

[10] Planning, evaluation, and studies area of the UPC. Statistics and Research Technical Unit of the Technical University of Catalonia

Research groups and centers in postgraduate studies

Detailed analyses of research and technological development in the energy field focused on the university major of Industrial Engineering. Since energy is a multidisciplinary area, in order to restrict the study to Industrial Engineering, a wide range of research areas were eliminated from the present analysis. Nonetheless, within Industrial Engineering, there is a considerable number of topics. Tables 19 and 20 collect the variety of lines of research and investigation groups in energy for the UPC, URV, and UdG.

R+D in the areas of energy and industrial engineering is concentrated at the UPC, in that most energy research is carried out in departments with strong ties to the Industrial Engineering School, but some is also carried out in the departments of Architecture and Telecommunications and in investigation centers: ICIMNE, Transport Study and Innovation Center, Barcelona Science Park, among others.

At the UPC, 17 lines of research were identified that consisted of energy-related (without taking into account lines exclusively related to the environment and energy). Most of these lines are attached to a single department, but interdepartmental research is also abundant.

To carry out a detailed analysis of R+D activities in energy and electrical technology for the 1996–2001 period, a representative set of groups in Industrial Engineering at the UPC were selected: departments of Machines and Thermal Motors, of Electrical Engineering, of Physics and Nuclear Engineering (DFEN), the Technological Center for Heat Transfer, the Institute for Energy Techniques (INTE). These groups were also evaluated in the previous research report.

Human resources: UPC

Total personnel per research line. If the human resources per line of research are analyzed, for all of the 17 lines of research at the UPC during 1996–2001, the average number of 15 varies between 2 and 37, and up to between 20 and 30 for those research lines in which different departments and the Technological Center for Heat Transfer participate. The participation of personnel is nominal in some cases.

Nine of the previously evaluated lines are related to activities in Industrial Engineering and are directed from the departments of Machines and Thermal Motors, Electrical Engineering, Physics and Nuclear Engineering, and centers or institutions that share human resources or infrastructures with the aforementioned departments, such as the Institute for Energy Techniques (Nuclear Engineering Section) and the Technological Center for Heat Transfer (Machines and Thermal Motors). A detailed analysis of these groups appears in the following section.

Personnel classification according to research group or center. It is difficult to evaluate the human resources exclusively dedicated to research in the different groups (centers or departments) and for each line. Most of the professors are not dedicated to R+D exclusively, as they have also administrative and teaching responsibilities. Nevertheless, a classification was established to consider as research staff the CU, TU CEU, and research personnel, in other words, personnel possessing a doctorate. The rest of the personnel of the departments or groups were classified as teaching staff (TEU and associated professoriate), interns, technical support personnel, and PAS. Full-time dedication was considered as the Equivalence of Full Dedication and part-time dedication was weighted as 0.5.

Table 22 shows the figures for 1996–2001 for groups in the field of Industrial Engineering: departments of Machines and Thermal Motors (Technological Center for Heat Transfer), Electrical Engineering, Physics and Nuclear Energy (DFEN), and the INTE.

The average number of investigators per group varies between 6.5 and 38, and their proportions within the different groups are similar, around 41%. The only exception is the De-

Table 19. Lines of research in energy areas: UPC

Scientific research areas at the UPC	*Department*	*N*[a]	*Theses 1997–2001*[b]
Environmental, energy, and natural resources			
Refrigeration techniques and air conditioning (3322990200)	724: Thermal Machines and Engines	2	2/1
Ignition and combustion in thermal engines and equipment; flame propagation; heat transfer; emission (3322990100)	724: Thermal Machines and Engines	9	2/0
Numerical simulation and experimental contrast of heat and mass transfer phenomena (3322040500)	724: Thermal Machines and Engines	18	5/0
Nuclear energy (332099700)	721: Physics and Nuclear Engineering 460: Institute of Energy Techniques	15	4/1
Thermal design and modeling of industrial equipment and components industrials (3313100400)	724: Thermal Machines and Engines	3	1/1
Project engineering (cogeneration) (3311020400)	736: Engineering Projects 713: Chemical Engineering	31	0/5
Architecture, energy, and services (3305010700)	720: Applied physics 704: Architectonic constructions	7	3/1
Resources, mining, the environment and its management (2506040100)	741: Mining Engineering and Natural Resources	13	0/3
Molecular alloys; energy storage (2213080500)	721: Physics and Nuclear Engineering	7	1/0
Architecture and Civil Engineering; Hydraulic Engineering			
Turbomachine systems (3313990200)	729: Fluid Mechanics	9	0/6
New experimental techniques and small-scale models in the study of hydraulic phenomena (dam and reservoir hydraulics) (330510200)	711: Hydraulic, Marine and Environmental Engineering	13	0/0
Production Technology			
Electric power systems (3306090100)	709: Electrical Engineering	24	8/1
Modeling, projects, and control of electric machines and components (336030100)	710: Electronic Engineering 709: Electrical Engineering	24	4/0
Semiconductor devises; solar energy (3307140000)	710: Electronic Engineering	19	2/8
Materials and technologies of analysis applied to construction and the environment (energy saving, energy auditing) (210601000)	736: Engineering Projects 721: Physics and Nuclear Engineering	6	0/2
Design, operation and control of chemical and biotechnological processes (energy and environment) (3303030100)	741: Mining Engineering and Natural Resources 724: Thermal Machines and Engines 715: Operational Statistics and Investigation 713: Chemical Engineering	37	4/10
Optimization and simulation of fluxes in networks (energy management). (1207100100)	725: Applied Mathematics 715: Operational Statistics and Investigation	16	2/2

[a] Number of personnel assigned to the line of research.
[b] Theses for the energy field / theses for other fields.
Source: UPC. Technical University of Catalonia.

Table 20. Lines of research in energetic technologies of industrial engineering at the URV and UdG

University	*Energy research area and groups*	*Lines of energy research*
Rovira i Virgili University	Chemistry, Engineering and Environment	Biomass, fuel biocells, closed and sustainable systems
	Center of Innovation in Biotechnology (DINAMIC)	Refrigeration technologies and heat bombs through absorption
	Center of Technological Innovation (CREVER). Research group of Applied Thermal Energy Engineering	Acclimatization and energy management of buildings Systems of distributed energy generation; integration of cold, heat and electricity production systems
University of Girona	Energy and Environment Department of Mechanical Engineering and Industrial Construction	CREMA: Renewable Energies and Environmental Research Group

Source: UR. Rovira i Virgili University. Catalogue of scientific-technologic offers
UdG. University of Girona. Research groups in the scientific and technical fields

partment of Electrical Engineering, where it is 22%, since the majority of personnel in this group are TEU-associated professors, i.e., dedicated to teaching. Overall, there is a low proportion of administrative and technical personnel –between 7 and 11% in the different departments. In the research institutes that were analyzed, support personnel accounts for 43% of human resources.

Economic resources: UPC

Financing of energy investigation in industrial engineering at the UPC. Table 23 lists the financing for the period 1996–2001. The analysis was based on data of the CTT of the UPC, for a set of representative groups in Industrial Engineering departments of Machines and Thermal Motors, Electrical Engineering, DFEN, the Technological Center for Heat Transfer, and the

Table 21. Departmental laboratories, research lines and centers at the UPC. Example 1: Department of Thermal Machines and Engines

Departments and Centers of the UPC	*Laboratories, research lines and centers*	*Total personnel (N)*
724: Thermal Machines and Engines	Thermodynamics and Physicochemistry Laboratory (Barcelona) Refrigeration and Acclimatization Experimental Center Thermal and calorimetric analysis Refrigeration and acclimatization	9
	Laboratory of Thermotecnia (Barcelona) Thermal design and modeling of thermal components and equipment Air conditioning	6
	Laboratory of Thermal Engines (Barcelona) Diesel combustion Hybrid vehicles	7
	Laboratory of Thermodynamics and Physicochemistry (Terrassa) Industrial energy management	1
	Laboratory of Thermotechnics and Energy (Terrassa) (see CTTC)	10
	Automobile and Thermal Engines Laboratory (Terrassa) Automobiles, biofuels, thermal turbomachines, Refrigeration and air conditioning	3
	Laboratory of Thermoenergetics (Terrassa) Thermal equipment and installations: low temperature solar energy, cogeneration.	3
	Laboratory of Fluid Mechanics and Thermal Engines (Manresa)	
928: Heat Transference Technological Center (CTTC)	Mathematical formulation, numerical resolution and experimental validation of heat and mass-transfer phenomena	26[a]
	Application of acquired know-how to optimization of thermal systems and equipment	
Total		35/9[b]

[a, b] Total personnel (N) of the Department of Thermal Machines and Engines on 2003 are of 35/7/2, professors-investigators, technicians and auxiliary staff, respectively. The total for the different laboratories is higher, given the shared activities of the professoriate, and the external personnel of the CTTC, which has 23 investigators.

Source: Department of Thermal Machines and Engines. UPC. The data for the 1996–2001 period are found in Table 22.

Table 22. Departmental laboratories, research lines, and centers at the UPC. Example 2: Nuclear Engineering Section of the Department of Physics and Nuclear Engineering

Departments of the UPC	*Laboratories, research lines and centers*	*ID/T+A[a]*
721: Physics and Nuclear Engineering. (Nuclear Engineering Section)	Nuclear Engineering Laboratory of Nuclear Fusion Engineering Nuclear fusion for magnetic confinement, Tokamaks, stellerators	7/3
	Thermohydraulics of nuclear reactors Safety in nuclear facilities	5/8
	Others Radioactive residues, radioisotope detection, particle accelerators	10/-
Total		12/11/2

[a] The total personnel for the Nuclear Engineering section in 2003 was 24 –12 doctors (ID), 10 technicians (T) and 2 assistants (A)– who in some cases were dedicated to different sublines of research. The data for all of the Department of Physics and Nuclear Engineering for the period 1996–2001 are found in Table 22.

Table 22. Statistics for research groups in electrical, thermal and nuclear energy: UPC (1996–2001)

	1996	1997	1998	1999	2000	2001	Annual average
Department of Electrical Engineering							
P.I.[a]	13	14	15	15	15	15	14.5
Teaching staff	43	41.5	41.5	41	41.5	49.5	43.0
Interns	1	2	3	5	5	3	3.167
PAS + support	4	4	5	5	5	5	4.667
Total personnel	61	61.5	64.5	66	66.5	72.5	65.33
These	4	2	3	4	4	9	4.333
JCR articles	1	0	2	6	1	1	1.833
Patents	0	0	1	1	0	0	0.333
Department of Machines and Thermal Engines							
P.I.[a]	11	14	21	21	22	22	18.5
Teaching staff	20.5	16	9	9	10	9	12.25
Interns	9	9	7	10	12	12	9.833
PAS + support	7	7	7	7	8	11	7.833
Total personnel	47.5	46	44	47	52	54	48.42
Theses	2	5	1	4	1	5	3.0
JCR articles	11	11	16	9	8	14	11.5
Patents	0	0	0	0	0	0	0.0
Department of Physics and Nuclear Engineering							
P.I.[a]	31	31	38	43	43	42	38
Teaching staff	46.5	45	38	32	32	37	38.42
Interns	2	4	5	7	10	10	6.333
PAS + support	10	11	10	10	10	10	10.167
Total personnel	89.5	91	91	92	95	99	92.917
Theses	5	8	4	3	5	4	4.833
JCR articles	55	50	67	58	84	59	62.17
Patents	0	0	2	3	1	0	1.0
Institute of Energy Techniques (INTE)							
P.I.[a]	7	6	6	6	7	7	6.5
Teaching staff	0	1	1	1	2	2	1.167
Interns	2	2	1	1	1	1	1.333
PAS + support	6	6	8	7	7	7	6.833
Total personnel	15	15	16	15	17	17	15.833
Theses	3	0	1	1	0	1	1.0
JCR articles	1	4	5	4	4	3	3.5
Patents	0	1	0	0	0	0	0.167

[a] Research staff, consists of professors, CU, CEU, TU and research doctors; teaching staff is defined as TEU professors and associated professors.
Source: Area of Planning, Evaluation and Research of the UPC. Statistics and Research Technical Unit.

INTE. Income is grouped according to transfer agreements, subsidies, national programs, and European programs.

The income for research programs is, on average, 54% of the total. The contribution from agreements, which generally represent a smaller component in basic research, is around 46%. The average annual total income per group is 1.3 million Euros, a similar figure to that of the 1990–1995 period, according to the IEC's research report. It should be highlighted that the financing for some groups (INTE or DFEN) is not exclusively dedicated to energy research, since they also carry out research in fundamental or applied physics.

The annual total R+D income per capita, in thousands of Euros and considering all personnel, varies between 1.4 and 14.7 depending on the group, and between 6.5 and 27.9 if the income per investigator is considered. The lowest figures correspond to those departments that have the dual function of research and teaching, and the highest to centers or institutions where research is the fundamental activity.

Results: UPC

The main indicators of R+D for the different groups are shown in Table 24, which presents a relative analysis of the, which sometimes reflect particular situations that contribute very little to the general state of R+D in the sector as a whole. All the same, as a group the figures do reflect the general R+D situation in Catalonia with respect to the activities of university groups in Industrial Engineering (electric and energy areas) during the years 1996–2001.

Theses per investigator. The number of theses per investigator and year varied between 0.127 and 0.299. The highest value corresponded to the Department of Electrical Engineering, which has a large number of non-research personnel due to its dedication to educational activity in the areas of technical engineering as well as to the scarce income for R+D, which in the last few years allowed the supervision of theses by the professoriate. The production of theses did not correlate either with R+D income or the groups' size. Thus, it seems that other

Table 23. Financing of electrical, thermal and nuclear energy groups at the UPC: Income during the period 1996–2001

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Average (thousands of Euros/year)*
Department of Electrical Engineering[a]							
Agreements	58.7	5.3	27.0	34.4	75.6	21.6	37.1
European programs	–	–	–	–	–	–	–
National programs	50.9	–	–	53.9	33.5	15.4	48.8
Others (subsidies, donations, etc.)	18,.3	–	29.5	–	–	–	79.7
Total	128.0	5.3	56.5	88.2	109.1	176.1	93.9
Department of Thermal Machines and Engines[b]							
Agreements	91.5	122.1	204.7	187.1	21.2	22.2	108.1
European programs	–	–	54.5	–	–	–	9.1
National programs	111.5	101.5	–	38.4	103.0	127.1	80.3
Others (subsidies, donations, etc.)	3.3	6.0	8.1	4.5	10.8	2.4	5.9
Total	206.4	229.6	267.3	230.0	135.0	151.7	203.3
Department of Physics and Nuclear Engineering[c]							
Agreements	137.0	314.7	195.7	152.2	114.0	117.9	171.9
European programs	80.8	38.5	–	–	196.7	–	52.7
National programs	113.7	132.8	192.7	426.1	64.4	362.1	215.3
Others (subsidies, donations, etc.)	–	–	2.4	–	–	–	0.4
Total	331.5	486.0	390.7	578.2	375.1	480.0	440.3
Heat and Mass Transfer Technological Centre (CTTC)[d]							
Agreements	58.3	161.1	7.8	209.8	120.2	–	92.9
European programs	–	129.4	708.5	–	6.0	–	140.7
National programs	11.4	–	142.4	437.5	69.7	54.1	119.2
Others (subsidies, donations, etc.)	–	4.8	–	189.3	–	–	30.9
Total	69.7	295.3	858.7	836.6	195.9	54.1	383.4
Institute of Energy Technologies (INTE)[e]							
Agreements	126.7	107.2	233.7	103.6	220.1	58.8	141.7
European programs	37.3	–	–	–	–	–	6.3
National Programs	41.1	–	17.6	69.3	–	74.5	33.8
Others (subsidies, donations, etc.)	–	–	–	–	-	–	–
Total	205.1	107.2	251.3	172.9	220.1	133.3	181.6

[a] Percentage of programs/total: 51.98 %.
[b] Percentage of programs/total: 43.94 %.
[c] Percentage of programs/total: 60.86 %. All research lines are included: energy as well as fundamental and applied physics.
[d] Percentage of programs/total: 67.75 %.
[e] Percentage of programs/total: 22 %. All research lines are included: energy and applied physics.
Source: Technology Transfer Center, UPC

Table 24. Main indicators for research in electrical, thermal and nuclear energy: UPC (1996–2001)

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Annual average*
Department of Electrical Engineering							
Theses/investigator	0.308	0.143	0.200	0.267	0.267	0.600	0.299
JCR articles/investigator	0.077	0	0.133	0.400	0.067	0.067	0.126
Theses/million Euros	31.25	380.0	53.1	45.3	36.4	51.1	46.2
Articles/million Euros	7.8	0	35.4	68.0	9.2	5.7	19.5
PI/total	0.213	0.228	0.233	0.227	0.226	0.207	0.222
Patents/investigator	0	0	0.067	0.067	0	0	0.023
Thousands of Euros/	–	–	–	–	–	–	6.47
investigator per person	–	–	–	–	–	–	1.44
Department of Thermal Machines and Engines							
Theses/investigator	0.182	0.357	0.048	0.19	0.045	0.227	0.162
JCR articles/investigator	1.0	0.786	0.762	0.429	0.364	0.637	0.622
Theses/million	9.69	21.78	3.75	17.39	7.41	32.96	14.75
Euros[a]	7.24	9.52	0.89	3.75	3.02	24.3	5.11
Articles/million	53.3	47.9	60.0	39.1	59.3	92.3	56.5
Euros[a]	39.8	20.9	14.2	8.4	24.2	68.0	19.6
PI/total	0.232	0.304	0.477	0.447	0.423	0.407	0.382
Patents/investigator	0	0	0	0	0	0	0
Thousands of Euros/	–	–	–	–	–	–	10.99
investigator per person	–	–	–	–	–	–	4.20

[a] Refers to both the department's income and the sum of the incomes from the department and the CTCC.

Table 24. Main research indicators for electrical, thermal and nuclear energy groups at the UPC: 1996–2001

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Annual average*
Department of Physics and Nuclear Engineering							
Theses/investigator	0.161	0.258	0.105	0.070	0.116	0.095	0.127
JCR articles/investigator	1.774	1.613	1.763	1.349	1.953	1.404	1.636
Theses/million Euros	15.08	16.46	10.24	5.19	13.33	8.33	10.98
Articles/million Euros	165.9	102.9	171.5	100.3	223.9	122.9	141.2
PI/total	0.346	0.341	0.418	0.467	0.453	0.424	0.409
Patents/investigator	0	0	0.053	0.070	0.023	0	0.026
Thousands of Euros/	–	–	–	–	–	–	11.59
investigator per person	–	–	–	–	–	–	4.74
Institute of Energy Technologies (INTE)							
Theses/investigator	0.429	0	0.167	0.167	0	0.143	0.154
JCR articles/investigator	0.143	0.667	0.833	0.667	0.571	0.429	0.538
Theses/million Euros	14.63	0	3.98	5.78	0	7.50	5.51
Articles/million Euros	4.88	37,33	19.90	23.13	18.11	22.51	19.27
PI/total	0.467	0.4	0.375	0.4	0.412	0.412	0.411
Patents/investigator	0	0.167	0	0	0	0	0.026
Thousands of Euros/	–	–	–	–	–	–	27.94
investigator per person	–	–	–	–	–	–	11.47

factors had a stronger influence on the production of theses, such as the promotion and training of teachers in the departments. It is also foreseeable that part of the research activity in the training phase acquires academic and vocational components that overcome structural and material difficulties.

Articles per investigator. The number of articles per investigator and year varied between 0.126 and 1.636. The production of articles per investigator correlated with R+D income and the number of investigators (size of the group), although there may have been other factors that also influenced output. The highest number of articles per investigator was in the Department of Physics and Nuclear Engineering, with research lines in energy as well as fundamental and applied physics, the weight of which was significant.

Theses per million Euros. The number of theses per million Euros and year varied between 5.1 and 46.2. The latter value, recorded for the Department of Electrical Engineering, was much higher than that of any other group and higher than the average for Catalonia (3.56). Moreover, the Department of Electrical Engineering is small with respect to investigators and financing. However, as previously noted in the section "Theses per investigator", this has encouraged the completion of theses and provides additional evidence that theses production does not correlate with either R+D or group size. The fact that this index does not depend on income suggests that most of the resources obtained for R+D are dedicated to the development of theses, probably because they come from technology-transfer activities, which do not posses sufficient innovative interest or scientific content to allow for the development of theses.

Articles per million Euros. The number of articles per million Euros and theses was similar in all groups and totaled 19. This figure was 141 for the Department of Physics and Nuclear Engineering, which, as previously mentioned, besides research lines in energy is also involved in fundamental and applied physics, whose contribution to scientific publishing is very high.

Human resources, economic resources, and results for other groups

As an example of new research groups in the energy field, the statistics and results from the Technological Innovation in Energetic and Refrigeration Revaluation Center (CREVER) of the URV are shown in Table 20 and Tables 25–27. The new groups share three well-defined characteristics: a strong institutional impulse, a consolidation process of teachers and research personnel, and a regional presence in the areas of technical advising services and investigation. The indicators of the results are different for the consolidation of teachers and research staff, which is why they were not considered in the global analysis. Even so, in this example, the evolution of the group consolidation stage can be seen, with very high production indexes.

Final considerations and conclusions

The data in this section were obtained from the databases, which cannot always be considered as complete.

General context. R+D, and more recently R+D+I in the energy sector, possesses two points of view, one of basic scientific character and the other (or many others) of applied technological character. Research in the former is not significantly represented in Industrial Engineering, whereas technological innovation and investigation –although scattered in multiple groups– is the object of ever-more structured activity. Such activity is

Table 25. Statistics of research in the Energetic and Refrigeration Revaluation Technological Innovation Center (CREVER), URV

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Annual average*
P.I.	1	2	2	3	4	4	2.667
Teaching staff	4	4	5	5	5	5	4.667
Interns	5	6	6	6	8	8	6.500
PAS + support	0	0	1	2	3	3	1.500
Total personnel	10	12	14	16	20	20	15.333
Theses	0	0	1	1	2	3	1.167
Articles	11	11	16	9	8	14	11.5
Patents	0	0	0	1	0	0	0.167

Source: CREVER (URV) 29/05/2004.

Table 26. Research financing in the Energetic and Refrigeration Revaluation Technological Innovation Center (CREVER), URV

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Annual average*
Agreements	–	–	24	62.6	36.7	59.4	30.5
European programs	–	–	–	45	45	–	15.0
National programs	9	9	60	222.1	198.6	251.4	125.0
Others (subsidies, donations)	22.4	14.6	12	31.8	105.6	83.4	45.0
Total	31.4	23.6	94	361.5	385.9	394.2	215.5

Source: CREVER (URV) 29/05/2004.

Table 27. Research indicators in the Energetic and Refrigeration Revaluation Technological Innovation Center (CREVER), URV

	1996	*1997*	*1998*	*1999*	*2000*	*2001*	*Annual average*
Theses/investigator	0	0	0.5	0.333	0.5	0.75	0.438
Articles/investigator	2.0	1.0	3.0	1.0	0.5	0.75	1.125
Theses/million Euros	0	0	10.6	2.77	5.18	7.61	5.42
Articles/million Euros	63.7	84.7	63.8	8.3	5.2	36.0	13.9
PI/total	0.1	0.17	0.14	0.19	0.20	0.20	0.17
Patents/investigator	0	0	0	0.333	0	0	0.06
Thousands of Euros per investigator per person	–	–	–	–	–	–	80.8

Source: CREVER (URV) 29/05/2004.

growing in those universities that offer a degree in Industrial Engineering (UPC, URV, and UdG).

Basic energy R+D requires considerable efforts, consolidated groups, and large investigation centers. Most of the investigation is carried out in the large energy companies and state-owned and European investigation centers.

In Catalonia, R+D in Industrial Engineering has developed due to small research centers and departments with little infrastructure, These share a combined financing derived from resources obtained from participation in state and European programs and, to a certain extent, from technology transfer or research for companies from the sector, which cannot always be considered as pure investigation.

The lack of administrative and technical support infrastructure, the reduced size of research groups, the double function of teaching-investigation, and the growing competition among universities, centers, and groups to obtain resources add more difficulties to the consolidation of groups.

Furthermore, since most R+D+I resources are dedicated to the sector's companies or to state-owned centers, the participation of university centers in large-scale investigation projects is restricted to collaborations, which are subject to specific objectives and terms, with a consequent loss of initiative.

The energy industrial sector

a) Conventional energy technologies

Energy is a strategic sector, and the closing, removal, or decline of companies involved in equipment and maintenance sector, due to market liberalization and the purchase of key technologies, contributes to the decline of the energy sector and the loss of qualified human resources, In the short-term, this leads to a loss of influence of technically oriented investigation –in response to lower employment expectations– and, ultimately to a system without technicians, academic personnel, investigators, and even knowledge. Areas such as electrical engineering, nuclear engineering, and combustion technologies thus find themselves in the middle of a vicious cycle.

In this cases, motivation from industry, universities, and government is needed to correct or relieve the situation, which is taking place in several countries and not only for the energy area, in which training fellowships and investigation aids are being provided in an attempt to ameliorate the situation.

b) Renewable energies and emerging technologies
Investigation in this field is disseminated in areas pertaining to physics, chemistry, electronics, biology, and agriculture, among others. While the national centers CIEMAT and CENER show the greatest potential, in general, centers of higher education and investigation in Industrial Engineering in Catalonia rarely participate in the development of these technologies. Notwithstanding, the Government of Catalonia, through the ICAEN, actively promotes them. In this context, the Research and Technological Development Promotion Program in the Energy Field, proposed by the Energy Plan for Catalonia on the Horizon of the Year 2010 (2002), which is currently under revision, can be a vehicle for stimulating initiatives in university centers.

The development of renewable energies is often given greater recognition than merited according to what has been achieved. This area of research benefits from a high level of economic stimulation and several fiscal advantages (in association with the environment) so that, in many cases, the amount of time assigned to research, product development, and field trials, supervised by companies and specialized centers in a very competitive field, has been shortened or moved ahead of schedule despite the evident lack of approval, materials, performance tests, and security standards. As a result, part of the productive stage of investigation lowers development and investigation costs.

Proposals of the Government of Catalonia to promote R+D in energy. The proposal of establishing a Research and Technological Development Promotion Program in the Energy Field, to be coordinated by ICAEN, emphasizes the need to establish a connection between university research groups, investigation centers, and companies in the energy field with the sources of financing and the energy technological market, with a focus on R+D in renewable energies area and energy efficiency.

It is also appropriate that the administration encourages the creation of a laboratory or the strengthening of already-existing laboratories, for calibration, testing, and approval of prototypes, especially for thermal or electric applications using renewable energies, and which can provide support to the investigation of prototypes.

It is probable that the promotion of investigation into conventional energies, with their challenges for efficiency and considering the general condition of the energy sector, is also necessary, as noted in the National Plan, at least to slow down the loss of human resources and expertise.

The organization of the Research and Technological Development Promotion Program in the Energy Field awaits political decision. The initiatives expounded are necessary and require encouragement from industrial sectors of the Government of Catalonia.

R+D in Higher Education in Industrial Engineering.

a) Research lines and groups
The main characteristic of investigation groups involved in research lines in the field of energy is, exceptions excluded, a reduced number of affiliated investigators, minimal support and auxiliary technicians (an endemic condition of investigation at universities), and the limited capacity of the respective laboratories.

The large number of research lines is partly due to the organization of training within the departments, and partly to the massive demand for investigation and reports concerning topics related to energy and the environment. The policy of the universities is to correct these anomalies by establishing criteria of size and production to match the number of research lines and groups.

b) Industrial Engineering centers
In the Industrial Engineering centers at the UPC, the main research lines in energy are carried out by the departments of Machines and Thermal Motors, Electrical Engineering, Physics and Nuclear Engineering (DFEN), the Technological Center for Heat Transfer, and the INTE.

At other Catalan universities with studies in industrial engineering (Rovira i Virgili University, University of Gerona), research groups are contained within several different departments.

c) Resources for investigation
Financing for research activities has lessened due to the new structure of the energy market. For example, R+D resources that came from energy tariffs have been eliminated. Fiscal aid to companies that carry out R+D is now aimed at environmental areas (and associated renewable energies), which in turn has caused the larger firms to increase their efforts in these lines of research. As a consequence, there has been a restructuring of energy research lines towards environmental ones.

Energy areas typical of Industrial Engineering are thus in an unfavorable situation or have been forced to reorient themselves towards environmental research. In superior education centers of Industrial Engineering, the situation is similar and has produced a standstill in R+D activity.

In general, R+D in the industrial energy field is applied research, mostly due to the small size of the groups and the training and preparation of the personnel.

If the five aforementioned UPC groups (which were also included in the last research report of the IEC) are taken as a sample, it can be verified that the average total annual income (1.3 million Euros) for the period 1995–2001 for I+D was similar to that of the previous period (1990–1995). The per capita R+D income of investigation centers and institutions is up to four times higher that of departments, and 2.5 times higher than the income per investigator, which confirms the fact that research during the last several years has experienced difficulties in establishing and generalizing its development. Most of the resources come from national and international R+D programs, which provide 54% of the funds. The rest of the income is from transfer agreements, typical of engineering services, and which are subject to confidentiality clauses that prevent both free access to the results and their diffusion in publications. For the period of study, the production of theses in the energy field was mostly unrelated to R+D income in the departments. This can be appreciated by the relation between theses and incomes in the departments of the energy field in Industrial Engineering. Part of the research activity in the training phase probably has an academic and vocational component, which overcomes the structural and material difficulties. However, the number of articles per investigator is in fact correlated with R+D income and the number of investigators (size of the group), but especially with the research lines of the groups, since production is lower in technological lines than in lines in applied or fundamental physics.

d) Challenges for the future

The evolution of R+D programs in the industrial energy sector is strongly conditioned by worldwide economic activity and by political decisions at all levels. Catalonia, for many years, has been in a difficult situation in this field. Factors such as industrial reorganization, liberation of energy markets, the ferocious competition to appropriate markets, the lack of infrastructure, the false or at least exaggerated expectations of some of the new energy technologies, are among the causes. In response to this outlook in R+D, research lines are being rationalized, according to initiatives of the National Plan for Energy from the National Plan of Scientific Investigation, Development and Innovation 2004–2007 and the Research and Technological Development Promotion Program in the Energy Field, as examples.

In the higher education field, whose participation in R+D in the energy field is comparatively small, the main challenges are: active participation in the R+D market, the training of investigators, and the maintenance of scientific and technical knowledge. Structural changes to improve the current situation are in the hands of the authorities.

Chemical Engineering, Textile and Paper Engineering, and Industrial Environmental Engineering

Characteristics of the field

The chemical industry is one of the most important sectors of the industrial field in Catalonia. According to data from the FEIQUE (Spanish Chemical Industry Federation) report for 2001, 44.7% of Spain's industry for this sector is located in Catalonia. Furthermore, Spain manufactures 7% of the European Union's chemical products; hence Catalonia represents 3.2% of the total European market production.

Moreover, this sector has a high number of productive subsectors, a total of 25 according to the same source of information, and includes everything from coarse industries such as oil refinement to finer chemical industries such as the pharmaceutical one. This implies a very diverse range of industrial activities, ranging from great multinationals to medium and small sized companies. This makes it difficult to track the research done the industrial sector of the chemical industry, since multinationals generally carry out research in their countries of origin, and companies that do research in our country, such as some related to fine chemistry, have imposed restrictions related to confidentiality of results, which impede access to data. It should be mentioned that some of research in the chemical industry is done in collaboration with public or private research centers, such as universities or the CSIC.

Another characteristic of this sector is the difficulty in establishing a borderline between research that is exclusive to Chemical Engineering and that which is related to other areas of chemistry, such as Basic Chemistry, Materials Science and Technology, etc. For this reason, analysis of the research centers reveals very diverse areas and topics, only some of which belong to or coexist with Chemical Engineering, or which are currently strongly related to it. Thus, this report has tried to exclude from its analysis of the field any research that is considered remote to Chemical Engineering.

The aforementioned diversity of the sector is reflected in the number of lines of research, research topics, or technology transfer covered by research centers in the field. For example:

- Optimization of chemical processes
- Chemical-plant safety and accident simulation
- Design and control of engines
- Water technology, urban and industrial sewage treatment
- Alimentary technology
- Industrial and radioactive waste treatment
- Biosensors
- Metal recuperation and/or separation techniques
- Pollutant analysis
- Heterogeneous catalysis
- Molecular engineering
- Synthesis and structure of polymers and technology of polymeric materials
- Biotechnology
- Transport phenomena

Similarly to the case of Chemical Engineering, the Textile and Paper Industry is also very important in our country, as can be seen by the fact that 48% of Spanish textile companies are located in Catalonia. Since most of the firms in this sector are small or medium sized, research and technology transfer are concentrated in a few centers, such as INTEXTER and DETIP, both of which are affiliated with the UPC, LEITAT, and LGAI. Thus, a few centers cover a broad spectrum of research lines, some of which are more related to Mechanical Engineering, Biotechnology, Textiles, or Paper. The following relation is illustrative of the great variety of research lines at these centers involved in technology transfer:

- Sewage treatment
- Ecotoxicology of water pollutants
- Biochemical and enzymatic studies related to textile or paper contamination
- Physicochemistry of dyes and finishings
- Multiple textile structures
- Textile polymers
- Development of expert systems for the automatic optimization of textile processes and systems

- Mechanical and computing applications destined to the development of clean technologies (recycling, product recuperation, bath regulations)
- Physicochemistry of tensoactive products
- Textiles for technical use.

Information Sources

Several information sources have been used to obtain quantitative data regarding the human and economic resources for both fields. Nonetheless, the diversity of these sources, their different structures, the availability of information, and, particularly for the industrial sector, their globalization have made it extremely difficult to develop this section of the report; mainly in relation to achieving a precise and exhaustive analysis of these two fields and of particular research or technological centers. This has also meant, that for some of the centers analyzed, the necessary information was not available. In addition, given the lack of correlation between the data and the source of information, the figures were not entirely reliable so that a certain amount of imprecision in defining the borderlines between the different areas could not be avoided.

The reference source of information was the research report of Industrial Engineering in Catalonia, edited in the year 1999 by the Institute for Catalan Studies. The other sources that were used depended on the context; thus, data referring to Catalonia was obtained from:

- Web pages of universities, technology transfer centers, postgraduate studies, and databases such as Fenix or GREC
- DURSI reports
- CIDEM reports and the CIDEM-CIRIT program

For Spain, the following information was used:

- Ministry of Science and Technology; reports of the National Plans of Scientific Research, Development, and Technological Innovation (1996–2002)
- Reports of the Cotec Foundation
- Technical Investigation Promotion Program (PROFIT)

Information referring to research and technological innovation in Europe was acquired from:

- The EUREKA net
- The Third European Report of Science and Technology Indicators (2003)
- Reports IV and V of the Research and Technological Development Framework Programs (1994–2002)

Furthermore, information related to articles in the analyzed fields was obtained and contrasted with:

- The Web of Knowledge from the Institute for Scientific Information (ISI)
- Journal Citation Reports

Research Groups and Centers

The following university departments and institutions were taken into account as research centers for Chemical Engineering:

- Chemical Engineering (Autonomous University of Barcelona, UAB)
- Chemical and Metallurgical Engineering (University of Barcelona, UB)
- Chemical and Agrarian Engineering and Food Technology (University of Gerona, UdG)
- Chemical Engineering (Technical University of Catalonia, UPC)
- Chemistry Institution of Sarria (Ramon Llull University, URL)
- Chemical Engineering (Rovira i Virgili University, URV)

All of them provided complete information for the period of the report.

Since some of these departments and institutions have research areas or groups that are related to other fields, such as Chemistry or Mechanical Engineering, and thus are discussed either in other reports, sections of this report, or areas as distant as Animal and Plant Production, our analysis was restricted, to the extent possible, to research groups involved in Chemical Engineering. Table 28 lists the different research areas and groups from these departments.

Out of all the areas that make up these departments, those that were distinctive or closely related to Chemical Engineering were selected according to the availability of information. Consequently, only data from Chemical Engineering at the University of Barcelona, the Autonomous University of Barcelona, and the University of Gerona were used in the report, since data from Ramon Llull University was employed by groups in Ecotechnology and Safety. In the case of Rovira i Virgili University and the Technical University of Catalonia, the data from all the areas belonging to the departments was used, since the main area in these universities is Chemical Engineering, and investigators from other areas carry out research that is strongly related to it.

For different reasons, the report has not considered the specific analysis of data from other institutions such as: research or development centers from the industrial sector, CSIC centers or specific centers (Fine Chemistry Processes Development Center, CDPQF). As previously explained, most of the companies related to the industrial sector are multinationals, which carry out research in their countries of origin. Those which are national only provide services, or do not carry out research, or have their research centers outside Catalonia. In addition, for some of these centers, their fields of research are more closely related to basic chemistry, or the confidentiality of their results, as in the pharmaceutical industry, make it difficult to obtain the information needed for a thorough analysis. Furthermore, the globalization of macroeconomic datain the industrial sector limits a precise and reliable study of this sector with respect to research and technological development. Also, research in CSIC centers clearly pertains to basic chemistry, and therefore is not included in this report.

Table 28. Areas of knowledge or research groups from the different university departments of Chemical Engineering

University	*Department*	*Area of knowledge/research groups*
UAB	Chemical Engineering	Chemical Engineering
UB	Chemical Engineering and Metallurgy	Chemical Engineering Materials Science and Metallurgic Engineering[b]
UdG	Chemical and Agrarian Engineering, and Agriculture Technology	Agrarian Economics, Sociology and Politics[a] Edaphology and Agricultural Chemistry[a] Agroforestry Engineering[a] Hydraulic Engineering[a] Chemical Engineering Animal Production[a] Plant Production[a] Food Technology[a]
UPC	Chemical Engineering	Chemical Engineering Analytical Chemistry Physics-Chemistry Organic Chemistry
URL	Chemical Institute of Sarrià	Engineering and Corrosion[a] Ecotechnology Biological Chemistry and Biotechnology[a] Analytical and Environmental Chemistry[a] Interdisciplinary Research Safety
URV	Chemical Engineering	Chemical Engineering Telematic Engineering Food Technology Operational Statistics and Investigation

[a] Included in the Materials Engineering field.
[b] Their data have not been included in the report.

Table 29. Consolidated quality research groups per center

UAB	*UB*	*UdG*	*UPC*	*URL*	*URV*	*DETIP*	*INTEXTER*
1	3	1	5	-	4	-	1

For Textile and Paper Engineering, the report was based on the analysis of data provided by INTEXTER and DETIP. Since this information made it difficult to separate areas related to Mechanical Engineering, such as Mechanic Textile Processes and Systems, it was considered as part of Textile and Paper. For similar reasons, data from groups belonging to Chemical Engineering area have not been included, but that part of their research related to the paper sector, such as the Laboratory of Paper Engineering and Polymer Materials (LEPAMAP), from the Chemical and Agrarian Engineering and Food Technology Department of the UdG, were included in the analysis of the Chemical Engineering.

Other centers that could have been related to the textile and paper sectors, such as the LEITAT or the LGAI, were not considered, given the difficulty in obtaining concrete information for their research activities. Research done by the industrial sector was not considered either, since, given the dimensions of most companies –small or medium sized– they do not posses specific research centers, and most of the research is done in centers already included in the report. Moreover, the data were dispersed or under confidentiality clauses, making them insufficient for a thorough study.

It should be mentioned that an important part of research ar these centers is devoted to the environment, for example:

– Chemical and Environmental Engineering Laboratory (LEQUIA) of the UdG
– Ecotechnology and Safety groups of the URL
– Environmental Management and Analysis Group (AGA) of the URV
– The Laboratories of Environmental Pollution Control and Environmental Toxicology of the INTEXTER (UPC)

Furthermore, an important part of the research done in the Chemical Engineering Department of the UAB is dedicated to the application of biotechnology to sewage water treatment, and part of the research at the UB is also included in this field. At the department of Chemical Engineering of the UPC, four specific research lines, out of a total of twelve, are dedicated to the environmental area –Risk and Environmental Impact Analysis, Study and Treatment of Industrial Residues, Environment and Water Technology, and Residue Management. Also, five sublines, included in the eight remaining lines, are also dedicated to research in aspects related to the environment. For this reason, the study of the evolution of the field known as Industrial Environmental Engineering for the period of the report is incorporated in the study of Chemical Engineering and Textile and Paper Engineering, since between them they thoroughly cover this other field.

Table 29 shows the different consolidated quality research groups from these centers according to data from the year previous to the report (2002). Regarding Chemical Engineering, the number of groups increased by 40% since 1995.

Human Resources

An analysis of human resources at the various research centers took into account the different types of personnel involved: full-time and part-time professoriate, investigators with and without a doctoral degree, visiting professoriate, interns, technical support personnel, etc. Since part of this personnel is not exclusively dedicated to research or is at its margins, such as administrative personnel, only professors and investigators were considered. As a reference value, in order to observe the evolution of this resource, the unit of Full Dedication Equivalent (EDP) –where 1 EDP = 1 professor or investigator working full time (TC)– was taken.

Tables 30 and 31 collect the available data for the different departments and institutes. Without considering personnel from the administration and services, an evolution can be seen for the total number of personnel in the groups, i.e., personnel exclusively dedicated to carrying out research, including support personnel –in the form of technical support personnel (PTS) or qualified support personnel (PQS)–, interns, and the corresponding EDPs. In the case of public universities, only interns with scholarships from the Ministry, of the Government of Catalonia or other non-university public organizations, were considered.

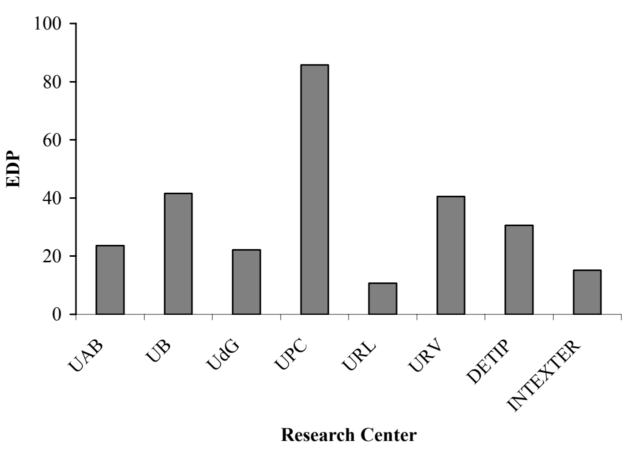

Figure 19. Size of the analyzed research centers. UAB, Autonomous University of Barcelona; UB, University of Barcelona; UdG, University of Gerona; UPC, Technical University of Catalonia; URL, Ramon Llull University; URV, Rovira i Virgili University; DETIP, Department of Textile and Paper Engineering (UPC); INTEXTER, Institute of Textile Research and Industrial Cooperation.

Table 30. Human resources at Chemical Engineering research centers

Research center		*Years*							*Average*
		1996	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	
UAB	Total personnel	36	38	38	43	41	52	48	42.3
	PTS/PQS	–	–	–	–	–	–	–	–
	Interns	9	9	10	8	7	11	8	8.9
	EDP	22.5	21	21.5	24.5	21.5	26	26.5	23.6
UB	Total personnel	–	–	–	–	–	–	–	48[a]
	PTS/PQS	–	–	–	–	–	–	–	–
	Interns	–	–	–	–	–	–	–	–
	EDP	–	–	–	–	–	–	–	41.5
UdG	Total personnel	23	25	26	29	27	27	27	26.3
	PTS/PQS	–	–	–	–	–	–	–	–
	Interns	–	–	–	–	–	–	–	–
	EDP	20.5	21	22	24.5	22.5	22.5	22.5	22.2
UPC	Total personnel	101	104	106	110	113	124	141	114.1
	PTS/PQS	–	–	0	2	6	5	4	3.4
	Interns	16	13	13	15	16	18	21	16
	EDP	77.5	82	84.5	83.5	82	89.5	101.5	85.8
URL	Total personnel	34	23	30	26	16	21	21	24.4
	PTS/PQS	1	1	1	1	0	0	1	0.7
	Interns	8	7	6	6	5	5	9	6.6
	EDP	12.5	10	13	11.5	9	10.5	8.5	10.7
URV	Total personnel	–	–	–	–	–	–	–	53[a]
	PTS/PQS	–	–	–	–	–	–	–	–
	Interns	–	–	–	–	–	–	–	–
	EDP	–	–	–	–	–	–	–	40.5
Total	Total personnel	–	–	–	–	–	–	–	308.1
	EDP	–	–	–	–	–	–	–	224.3

– There were no available data
[a] Only investigator-teaching staff has been counted

Table 31. Human resources at the DETIP and INTEXTER

Research center		1996	1997	1998	1999	2000	2001	2002	Average
		Years							
DETIP	Total personnel	41	34	32	33	32	33	–	34.2
	PTS/PQS	–	–	0	0	0	0	–	0
	Interns	2	2	1	3	3	5	–	2.7
	EDP	37.5	31.5	30.5	29.5	28.5	26.5	–	30.7
INTEXTER	Total personnel	22	17	17	15	16	16	–	17.2
	PTS/PQS	–	–	0	0	0	0	–	0
	Interns	4	2	2	2	1	1	–	2
	EDP	18	15	15	13	15	15	–	15.2
Total	Total personnel	63	51	49	48	48	49	–	51.4
	Interns	6	4	3	5	4	6	–	4.7
	EDP	55.5	46.5	45.5	42.5	43.5	41.5	–	45.9

– There were no data available.

In the case of the UB and URV, since data for this period were not available, figures of total personnel and EDPs for the 2003–2004 period were employed as the reference for the subsequent analysis of results.

Figure 19 shows the size of the departments and institutions analyzed in this report. It can be seen that the analysis includes research centers of very different sizes. The Department of Chemical Engineering of the UPC, given its macrostructure (three territorial department sections, participation in teaching and research in four technical schools and four superior schools, etc.), with approximately 86 EDPs, can be considered as large. Three departments can be considered medium-sized, those of the UB, URV, and DETIP, as they have around 30 or 40 EDPs. The rest can be considered small, ranging in size from 10 to 20 EDPs.

The evolution of EDPs in Chemical Engineering is shown in Fig. 20. There was an increase at the UPC and the UAB (18% and 10%, respectively, above the average values for the last year), a standstill at the UdG, and a slight decrease at the URL. The increase at the UPC and the UAB, nevertheless, was due more to teaching necessities –new qualifications such as Chemical Engineering at the UPC began during the mentioned period– than to research needs. Moreover, the average increase during this period was 13%, below the average EDP increase in the area of science and technology in Spain and the European Union (30% and 24%, respectively).

In the same analysis for the EDPs of Textile and Paper, the data in Table 31 show a standstill for INTEXTER during practically the entire period of the report, and a decrease for DETIP that began in 1999, i.e., 4% below the average and 14% in 2001.

Analysis of the evolution in the number of interns per EDPat the Chemical Engineering research centers during the period of the report (Fig. 21) revealed a noticeable difference between centers. The group at the URL maintained an relation between 0.46 and 1.06, with an average of 0.61; the UAB had a relation between 0.3 and 0.47, with an average of 0.37 and the UPC was the most stable, with values between 0.15 and 0.21 and an average of 0.19. This is due to the fact that, in public universities, only interns with scholarships from non-university official

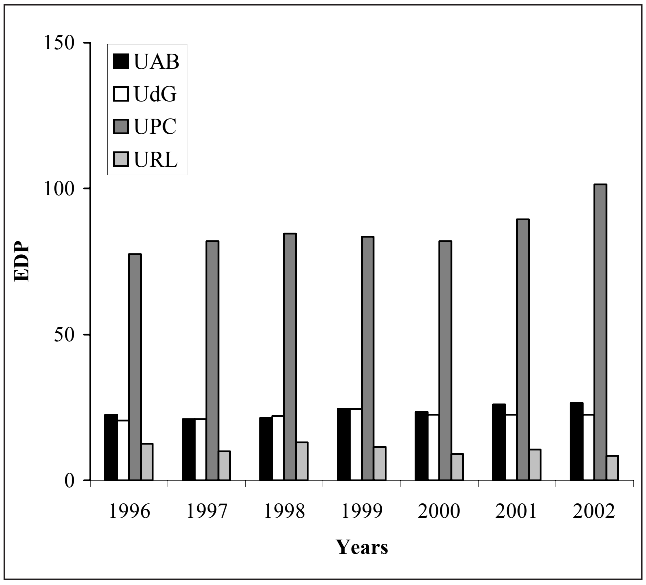

Figure 20. Evolution of the equivalents of full-time dedication (EDPs) in the Chemical Engineering departments of the UAB, UdG, UPC, and URL.

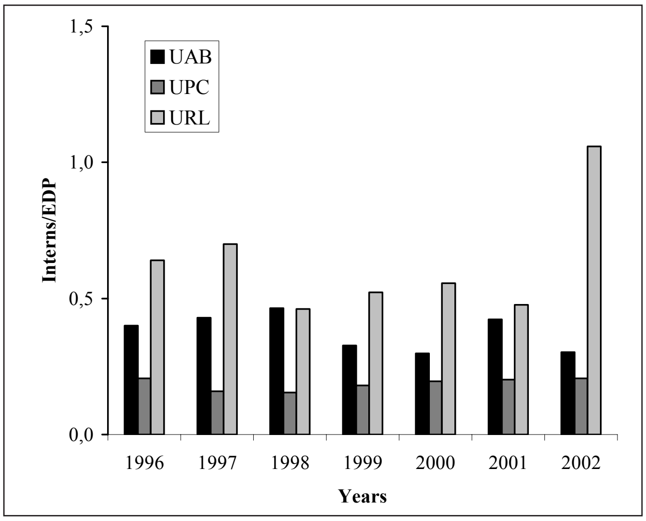

Figure 21. Evolution of the intern/EDP relationship in the Chemical Engineering departments of the UAB, UPC, and URL.

organizations were taken into account, and not those interns appointed through specific agreements, e.g., with companies. This restriction was not introduced in the case of the URL.

If the second category of interns was taken into account, the figures for the UAB, for example, would be twice as large, and the relation with be approximately the same as that of the URL. A similar situation would be seen for the UPC.

The same representation for INTEXTER and DETIP (Fig. 22) shows two opposing situations. While INTEXTER had an important decrease during the period of the report, DETIP experienced significant growth, especially during the last year, not only due to the decrease of EDPs in the center. All the same, the number of interns per EDP was even smaller than in Chemical Engineering centers, with average values of 0.13 for INTEXTER and 0.09 for DETIP.

Figure 23 shows the evolution of the relation between PTS and EDPs. Before analyzing the data, it should be mentioned that: (1) this type of personnel does not appear at public universities as such until 1998; (2) personnel is co-financed, as the research group covers 50% of their costs; (3) their contract is limited to a maximum of 3 years. All of this limits their incorporation, as can be seen in the figure in the case of the UPC, the only public center from which annual contracting data since 1998 were available. The decreasing tendency in hiring such personnel over time is obvious. Nonetheless, the relation of values between 0.02 and 0.07 for the UPC and between 0.08 and 0.12 for the URL is very similar to that in Spain, 0.08. This relation shows a deficiency of this type of personnel in both Catalan and Spanish research centers compared to the average technical support personnel per EDP in countries of the European Union, such as Germany, France and the UK, where it is of 0.4.

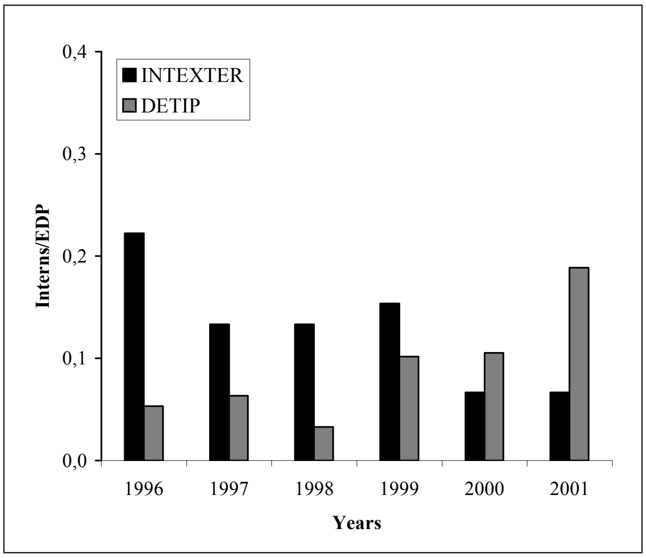

Figure 22. Evolution of the intern/EDP relationship at INTEXTER and DETIP.

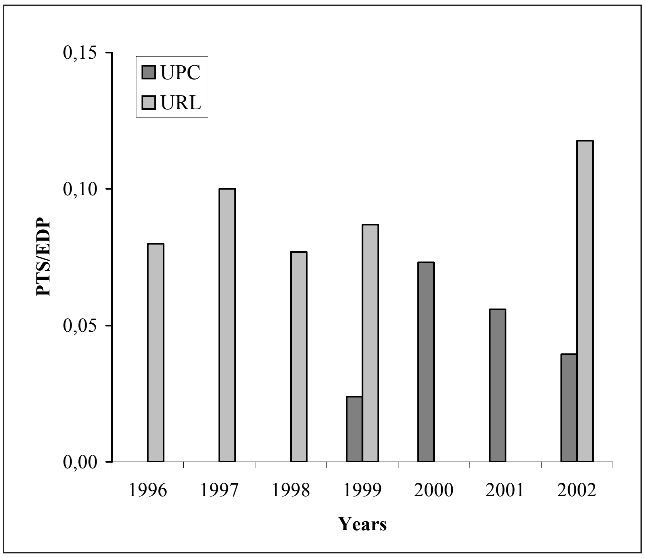

Figure 23. Evolution of the ratio technical-support personnel (PTS)/EDP in the Chemical Engineering departments of the UPC and URL.

Economic Resources

Three types of economic resources have been considered: those obtained from projects and aid financed by the Spanish and Catalan Governments, designated as public funds; those obtained from European projects; and those coming from agreements and services with companies and public or private institutions. The resources obtained for continued training and financing with funds from the university to which the research center belongs were not included.

Tables 32 and 33 present data concerning these resources. For some European projects, their total financing was considered in the year it was awarded.

Figure 24 shows the global distribution of resources received during the period of the report for the two fields. While the distribution differed greatly between them, in both cases economic resources were deficient compared to those of the average Spanish university, where 55.5% of economic resources came from a public source, 23.5% from European projects, and the remaining 21% from agreements and services.

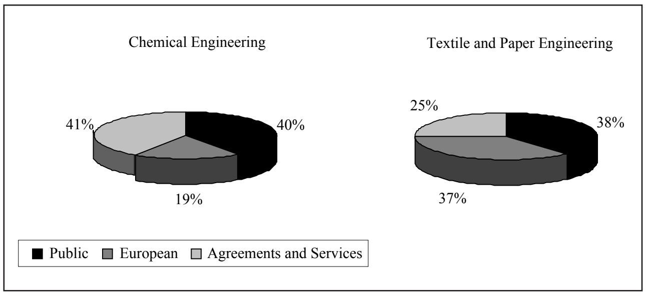

Figure 24. Comparison of funding resources in the fields of Chemical Engineering and Paper and Textile Engineering

For Chemical Engineering in public universities, on average, 40% of the resources came from public financing, varying between 33.9% for the UB and 55.6% for the UdG. By contrast, only 13% of the financing obtained by the URL –a private university– came from state or autonomous funds. However, an analysis of the distribution of resources obtained through agreements and services with companies and institutions –41% on average– shows that the percentage in public centers varied between 32.8% for the UPC and 49.3 for the UAB, while

Table 32. Economic resources (in thousands of Euros) of the research centers in Chemical Engineering

Research center		1996	1997	1998	1999	2000	2001	2002	Average
UAB	Public	85.4	443.7	142.4	210.6	330.1	723.1	306.8	320.3
	European	424.3	13.4						62.5
	A/S	171.5	232.2	146.8	476.7	445.5	512.9	618.2	372
	Total	681.2	689.3	289.2	687.3	775.6	1236	925	754.8
UB	Public	238.1	194.3	291.5	176.1	342.8	346.8	399.3	284.1
	European	112		399.3		342.6	220	198.5	181.8
	A/S	491.2	247	294.8	371.5	406	212	590.4	373.3
	Total	841.3	441.3	985.6	547.6	1091.4	778.8	1188.2	839.2
UdG	Public	183.2	259.4	256.6	321.5	358.5	542.1	591.7	359
	European	39.9	13.7	30.9	31.3	13.6	83.8	20.3	33.4
	A/S	74.1	71.3	214.5	256.9	328	395.5	352.3	241.8
	Total	297.2	344.4	502	609.7	700.1	1021.4	964.3	634.2
UPC	Public	356.2	280.3	271.4	1085	306.6	386.7	488.8	453.6
	European	73.6	242.6	229.8	176	915.3	18	383.2	291.2
	A/S	276.5	244.2	320.3	659	371.6	265.1	409.5	363.7
	Total	706.3	767.1	821.5	1920	1593.5	669.8	1281.5	1108.5
URL	Public	36.6	36.6	16	33	38	22	5	26.8
	European	28.4	39.6	20.1	50	50	72.5	86.9	49.6
	A/S	176	150.2	117.8	105.6	64.8	113.4	176.1	129.1
	Total	241	226.4	153.9	188.6	152.8	207.9	268	205.5
URV	Public	172	321.1	205.2	194.5	452.2	375.8	599.7	331.5
	European		191.3		197.5		386.5	752.8	218.3
	A/S	143	339.1	654.6	343.6	276.7	253.2	191.8	314.6
	Total	315	851.5	859.8	735.6	728.9	1015.5	1544.3	864.4
Total	Public	1071.5	153.4	1183	2020.7	1828.2	23965	2391.3	1775.3
	European	678.2	500.6	680.2	454.8	1321.4	780.8	1441.7	836.8
	A/S	1332.3	1284	1748.8	2213.3	1892.7	1752.1	2338.3	1794.5
	Total	3082	3320	3612	4688.8	5042.3	4929.4	6171.3	4406.6

– There were no data available.
A/S indicates agreements and services

Table 33. Economic resources (in thousands of Euros) of the DETIP and the INTEXTER

Research center		1996	1997	1998	1999	2000	2001	2002	Average
DETIP	Publican	132.9	18	58.5	90.8	68.1	204.5	–	95.5
	European					122.6		–	20.4
	A/S	2.3	44.8	78.2	89.5	184.5	36	–	72.6
	Total	135.2	62.8	136.7	180.3	375.2	240,5	–	188.5
INTEXTER	Publican	114.9	735.3	12.1	200.7	168.4	398.3	–	271.6
	European	1285.5		113.7			587.2	–	331.1
	A/S	55.4	139.4	137	167.7	131.4	368	–	166.5
	Total	1455.8	874.7	262.8	368.4	299.8	1353.5	–	769.2
Total	Public	247.8	753.3	70.6	291.5	236.5	602.8	–	367.1
	European	1285.5		113.7		122.6	5874	–	351.5
	A/S	57.7	184.2	215.2	257.2	315.9	404	–	239.1
	Total	1591	937.5	399.5	548.7	675	1594	–	957.7

– There were no data available.
A/S indicates agreements and services

at the URL they represented 62.8% of the total. Financing by means of European projects represented an average of 19%, ranging from 5.3% at the UdG to 26.3% at the UPC.

An analysis of Textile and Paper Engineering showed that the average values of economic resources from European projects and of agreements and services differed greatly from those recorded in Chemical Engineering. This was mostly due to the distribution of resources received by INTEXTER during the period of the report. At INTEXTER, 35.5, 43, and 21.7%, respectively, of financing came from public, European projects, and agreements and services, while at DETIP of the distribution was 50, 11.5, and 38.5%, respectively, similar to that of Chemical Engineering.

Despite the oscillatory character of the evolution of economic resources over time, especially from European funds, certain tendencies were observed. Figure 25 shows this distribution for all of the research centers in Chemical Engineering and makes clear a growing trend regarding total resources received during the period of the report. There was, nonetheless, a relative standstill during the last few years of the current period. It should be highlighted that the average annual financing for this period was of 4.41 million Euros, more than three times higher than the average annual financing received by these centers (1.35 million Euros) from the same sources during 1990–1995, according to data from the Industrial Engineering in Catalonia research report of 1999.

When this distribution was analyzed for the research centers in Textile and Paper Engineering, the behavior was found to differ greatly from that of Chemical Engineering (Fig. 26). In this case, the distribution over time showed an important decrease in the resources obtained from the start to the middle of the period of the report, with a subsequent recuperation. This tendency was mainly due to financing from European projects –which was concentrated at the beginning and end of the period– and partly to financing from public funds. By contrast, resources from agreements and services grew throughout the entire period.

Compared to the previous report, average annual financing clearly dropped: average resources obtained was around one million Euros for this period, whereas between 1990 and 1995 it was around two million Euros.

Summarizing, resources obtained by Catalan firms, from public or European funds, to develop R+D during this period had an annual average of about 22 million Euros for the chemical industry and 3.5 million Euros for the textile and paper industry.

Figure 27 shows the average annual financing per EDP according to by research center during the period of the report. The data were broken down into the different sources of financing and the total economic resources received. There was an inverse proportion between the size of the center –number of EDPs– and the funds received per EDP, and this was independent of the field analyzed. Thus, for Chemical Engineering, the UPC had an total resource average of 12 900 Euros per EDP, while the UAB and the UdG had averages of 32 000 and 28 600 Euros per EDP, respectively. In the case of Textile and Paper Engineering, the gap was even larger between the financing received by INTEXTER, 50 600 euros per EPD, and by the DETIP, 6100 Euros per EDP.

The figure also shows that public funding of EDPs at Catalan research centers in the two fields varied between an average of2500 Euros per EDP for the URL and 17 900 Euros per EDP at INTEXTER. Also, financing for European projects varied between the 700 Euros/EDP for the DETIP and 21 800 Euros/EDP for INTEXTER. Financing from agreements and services comprised between 2400 Euros/ EDP for the DETIP and 15 800 Euros/EDP for the UAB.

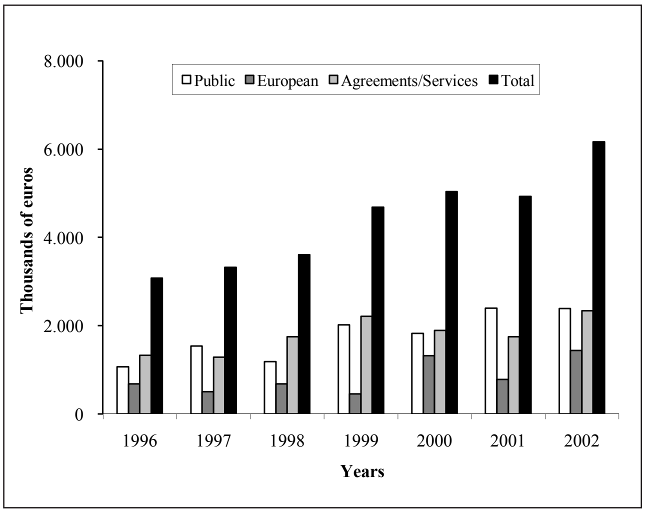

Figure 25. Distribution of economic resources for all the Chemical Enginnering centers.

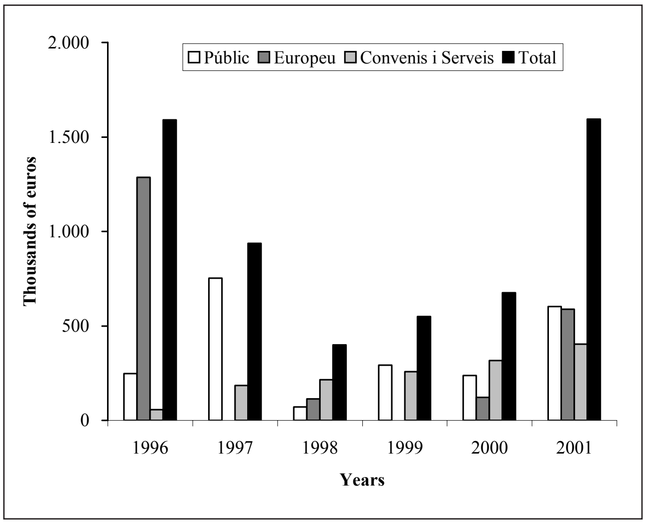

Figure 26. Distribution of economic resources for the Textile and Paper Engineering centers.

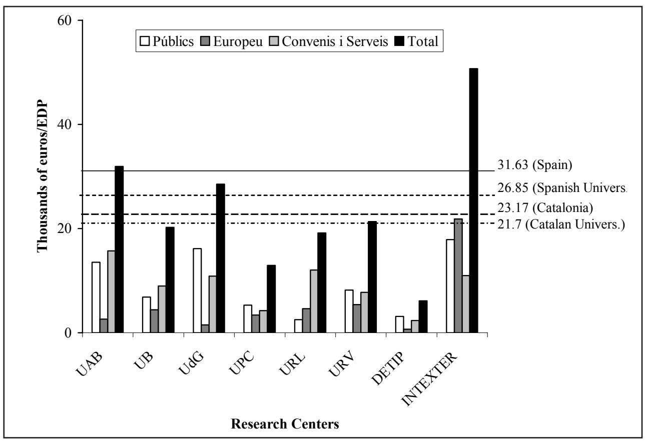

Figure 27. Economic resources per EDP for the different research centers.

The global averages for both areas were very similar: 19 650 Euros/EDP for Chemical Engineering and 20 870 Euros/EDP for Textile and Paper Engineering. Both averages are close to those of Catalan university centers (21 700 Euros/EDP) and slightly below the average of Spanish university centers (26 850 Euros/EDP). However, the comparison proves to be more unfavorable if the averages of university centers are compared with those of public administration centers: 23 170 Euros/EDP for Catalonia and 31 630 Euros/EDP in Spain. Furthermore, these averages are also below those of other countries from the European Union, such as Germany, France and the UK (47 000 Euros/EDP) and much below the Swiss average of 85 000 Euros/EDP.

Results

When research output in the analyzed centers was evaluated, only two types of results were considered as being the most representative: doctoral these and articles in indexed journals of the Journal Citation Report. Other contributions, such as patents, congresses, and books, were not considered due to the scarce availability of the respective data and the difficulty in judging their scientific or technical merit. Tables 34 and 35 present data referring to doctoral these and indexed articles for the different research centers.

It should be emphasized that scientific output by research centers in Chemical Engineering strongly increased during the period of this report compared to the previous period. The annual average of theses during the current period was of 32.9, while the average for 1990–1995 was 11.3, approximately three times less. The increase in the number of articles in indexed journals was even more significant, around four times more than the previous period(49.3 articles on average during 1990–1995 and an annual average of 195.1).

By contrast, in Textile and Paper Engineering, output decreased compared to the previous period, at least for data regarding the number of theses at the DETIP, where the annual average during 1990–1995 was of two theses, compared to an average of 1.5 for the period covered in the current report.

Figure 28 shows the average annual number of theses per EDP from centers in both fields. The averages fluctuated between 0.05 theses per EDP for the DETIP and 0.19 theses per EDP for the URV. Although there was a large difference between the most extreme values, most of the other centers (UAB, UB, UPC, URL and INTEXTER) had an average around 0.15-0.13 for the UPC and 0.17 for the URL. All the centers analyzed in the report, excluding the DETIP, which was slightly below, were above the average of Catalan university centers

Table 34. Research output in Chemical Engineering

Research center		*Years*							*Average*
		1996	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	
UAB	Theses	2	2	5	3	6	6	2	3.7
	Articles	12	18	12	10	10	9	16	12.4
UB	Theses	6	7	10	7	3	10	4	6.7
	Articles	37	35	32	32	30	20	33	31.3
UdG	Theses	0	5	2	2	2	2	0	1.9
	Articles	10	11	3	10	12	14	11	10.1
UPC	Theses	12	10	9	11	8	16	11	11
	Articles	66	80	102	92	96	91	70	85.3
URL	Theses	2	4	3	2	1	1	0	1.9
	Articles	6	4	9	6	1	1	1	4
URV	Theses	3	5	4	7	8	9	18	7.7
	Articles	55	46	42	63	45	43	70	52
Total	Theses	25	33	33	32	28	44	35	32.9
	Articles	186	194	200	213	194	178	201	195.1

– No data were available.

Table 35. Research output at the DETIP and INTEXTER

Research center		*Years*							*Average*
		1996	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	
DETIP	These	0	1	2	1	1	4	–	1.5
	Articles	5	7	3	11	11	13	–	8.3
INTEXTER	These	0	1	3	5	1	5	–	2.5
	Articles	3	7	3	10	7	13	–	7.2
Total	Theses	0	2	5	6	2	9	-	4
	Articles	8	14	6	21	18	26	–	15.5

– No data were available.

where the relation was 0.15 theses/EDP. In conclusion, the global averages for both fields were above the Catalan average, with 0.15 theses/EDP for Chemical Engineering and 0.09 theses/EDP for Textile and Paper Engineering.

The annual average number of articles published per EDP at centers from both fields of engineering is shown in Fig. 29. In this case, the difference between the two fields was quite large; moreover, the maximum and minimum values of this average corresponded to the same center. Thus, the DETIP had an average of 0.27 articles/EDP while at the URV the average was 1.28. The DETIP average WAS slightly below that of Catalan university centers 80.32 articles/EDP) but the same as the average of Spanish university centers (0.27 articles/EDP). All the other centers were above this average, particularly the UPC and the URV, where the average was 3 and 4 times higher, respectively.

In Chemical Engineering, the global average was much higher than the Catalan and Spanish averages, i.e., 0.87 articles/EDP, and not that much lower than the 1 article/EDP average of Germany, France, and the UK. The average of 0.34 articles/EDP in Textile and Paper Engineering was very similar to the Catalan average, and above the Spanish one.

Although it is not completely representative of the quality of theses from a center, since articles that are not related to the results of a thesis can also be published, an analysis of published articles per thesis is instructive. Figure 30 shows this relation for centers in both fields. There were 7.8 articles/thesis for the UPC but only 2.2 articles/thesis for the URL. If this relationship is compared to the global figures of Catalan and Spanish university centers (3.9 and 3.5, respectively), we see that in five of Catalan centers (UB, UdG, UPC, URV and INTEXTER) the values are higher than those of Spain, while in the remaining centers it is less. Notwithstanding, both fields had global values above those of Catalonia and Spain, with 5 articles/thesis for Chemical Engineering and 4.25 articles/thesis for Textile and Paper Engineering.

Figures 31 and 32 reflect the economic return of scientific output for both sectors, per research center, theses completed, and articles published per million Euros of the total resources. Excluding the return for theses completed at the URV, there was a direct relation between the size of the center, in terms of number of EDPs, and return; hence, there is a better use of economic resources at medium or large sized centers, such as the UPC, which has the highest output in the field of

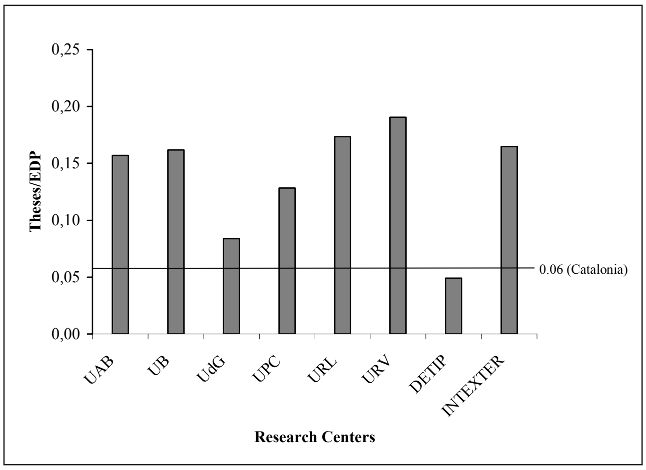

Figure 28. Annual average number of theses per EDP at the different engineering centers for the period 1996-2002.

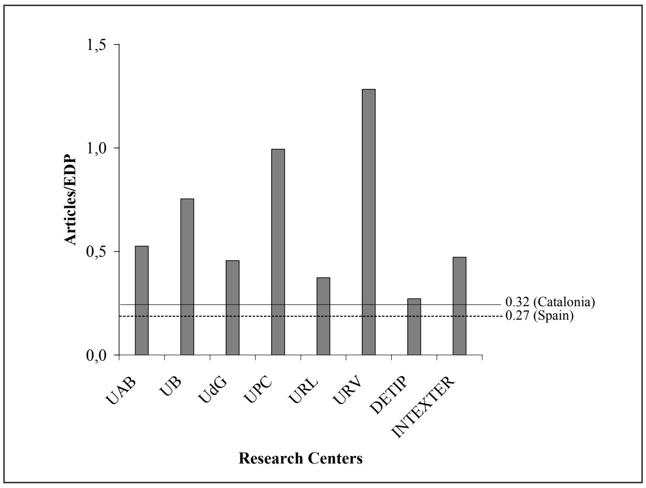

Figure 29. Annual average number of articles published per EDP at the different research centers for the period 1996-2002.

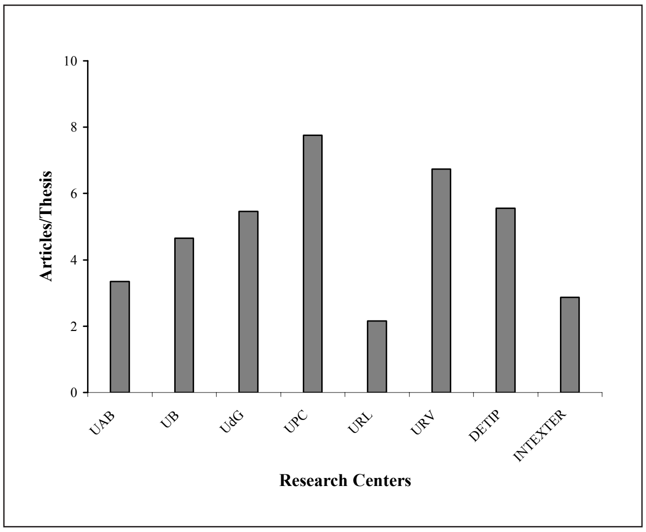

Figure 30. Articles published per thesis at the different engineering centers.

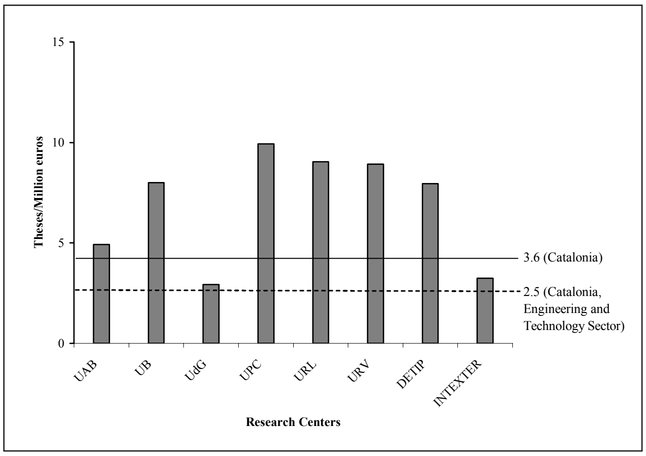

Figure 31. Theses completed at the different research centers per million Euros of total economic resources.

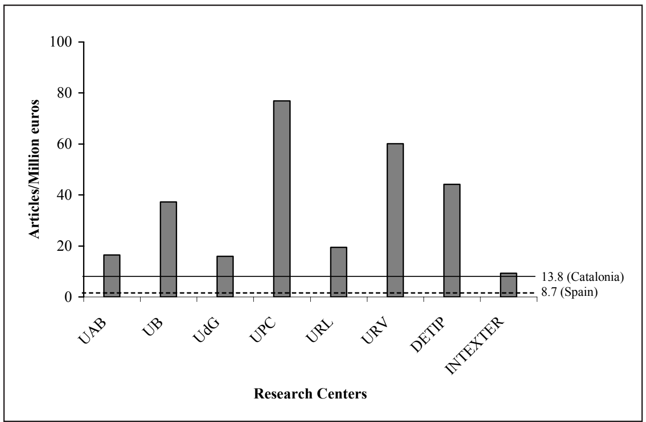

Figure 32. Articles published by the different research centers per million Euros of total economic resources.

Chemical Engineering (10 theses and 77 articles per million Euros), or the DETIP (8 theses and 44 articles per million Euros) than at large centers such as INTEXTER.

If the return results of theses from these centers are compared with those of Catalan university research centers, where the average is 3.6 theses per million Euro), then, except for the UdG and INTEXTER (2.9 and 3.3 theses/million Euros respectively), the return is above average. Furthermore, the return at all of the analyzed centers was above the average of university research centers in the area of Engineering and Technology (2.5 theses/million Euros). Both sectors had a high global output of theses in relation to economic resources, i.e., 7.3 theses/million Euros in Chemical Engineering and 5.5 theses/million Euros in Textile and Paper Engineering.

If the same comparison is made regarding the publication of indexed articles, except for INTEXTER, with an average of 9 articles/million Euros (similar to the average 8.7 of Spanish university research centers), the output of all of the centers was over 13.8 articles/million Euros, which is the average of Catalan university research centers. This means that the global return in both fields was above average. For Chemical Engineering (37.5 articles per million Euros), it is three times higher than the Catalan average and two-fold higher in the case of Textile and Paper Engineering (26.5 articles per million Euros).

Final Considerations and Conclusions

Although there are numerous information services and databases as well as several ongoing analyses of current information and the technology that facilitates transfer of this information, the collection of data and its subsequent treatment have become widely scattered, especially as pertains technological innovation and technology transfer in the industrial sector. This is also the case in Chemical Engineering and Textile and Paper Engineering. Thus, a precise analysis of the evolution of technological innovation and developments in industrial areas is difficult.

The diversity of information sources hinders an analysis of the evolution of research even in those centers that have more exhaustive information. Other problems are the lack of data for certain indicators, the way in which the data are presented, the use of several different indicators, especially when boundaries between areas are difficult to distinguish, and comparisons of results obtained by different sources. Thus, the conclusions taken from this report should not be considered as absolute, but rather guidelines. In future reports, it is advisable that the Administration regulate the collection of information by introducing uniformity in the indicators and clear-cut contrasts of data deriving from different sources of information.

For both fields, there in general, there was a standstill regarding human resources at the research centers during the period of this report. While some Chemical Engineering centers, such as the UAB or the UPC, experienced growth, it was nonetheless below the averages of Spanish or European research centers. Other centers remained deadlocked or had a slight decrease towards the end of the report period. The consequence has been that the global average of growth in Chemical Engineering was practically half of the Spanish and European averages. In the case of Textile and Paper Engineering, the standstill situation of INTEXTER and the decrease at the DETIP imply a significant loss of human resources for this field.

According to the centers from which information was available, only a few interns were subsidized by the Civil Service. The relation between interns and EDP shows that this resource insufficiently contributes to public centers for either field. This leads to the centers having to cover deficiencies regarding subsidized interns through other economic means, and thus creates a dependency of research on the private sector. This, in principle, can be very positive, since it establishes a relationship between public research centers and the business environment; but there are also inconveniences, such as the difficulty in agreeing on common grounds for technological development between centers and firms, or that, given their characteristics, the companies only require services or applied technology transfer, and thus nothing new is contributed to development. Furthermore, in this case associated personnel or interns, do not dedicate their time to research, but rather to tasks related to services derived from the agreement; thus, the most is not made out of these resources for technological innovation.

Another observed deficiency, in relation to human resources, has to do with technical support personnel. This deficiency seems to be a chronic problem of the research system in Spain, since the average PTS/EDP relationship for the entire country is five times below that of other European countries, such as Germany and the UK. However, actions taken by public centers, i.e., co-financing and temporal contracting of this type of personnel fora maximum of 3 years, does not seem to have solved this deficiency. According to the data, there was no hiring of this type of personnel, and in the only center that had evidence of this type of contracting –the UPC– there was a decreasing tendency, probably derived from the aforementioned problems of co-financing and temporality.

The evolution of human resources varies greatly, not only among the different fields but also between centers of the same field. In the case of Chemical Engineering, there was a tendency toward growth of total resources received during the period of the report from the different sources of financing, but a certain impasse occurred in the last years of the period.

Moreover, average annual financing during this period was more than three times greater than the average annual financing received by these centers, from the same sources, during 1990–1995. For Textile and Paper Engineering, the behavior was very different from that of Chemical Engineering in that there was an important decrease in the resources obtained over time, from the beginning to the middle of the period, but with a subsequent recuperation.

With regards to the distribution of resources at the different centers, the index measuring thousands of Euros/EDP shows an inverse relationship between the size of the center and the expenditure per EDP, which is independent of the field analyzed. There was also a great oscillation within this index for both total economic resources and different sources of financing. The global averages of total economic resources received per EDP for both fields were very similar, and both were close to the average of Catalan university centers, but below the averages for Catalonia, Spain, and Spanish university centers. They were also below half the average of countries such as Germany, France, and the UK.

Scientific output for Chemical Engineering research centers strongly increased during the period of this report compared to the 1990–1995 period: the average annual number of theses completed was three times higher than in the previous period. More important was the increase in the number of articles in indexed journals, which was four times higher than in 1990–1995. However, the number of completed theses in Textile and Paper Engineering was lower than in the previous period, e.g., by 33% at the DETIP.

Scientific output at Chemical Engineering centers varied according to the size of the center, with a substantial difference between small centers vs. medium and large ones. Despite the fact that some of centers, such as the UAB or URL, have a long tradition in the field, their critical mass of personnel has not increased sufficiently to match the results of other centers. This is confirmed by comparing the two newest centers, the UdG, which is small, and the URV. Still, the average numbers of theses completed and articles published per EDP at all centers in this field are above those of Catalan and Spanish university centers. Moreover, the annual average number of articles published per EDP is not much less than the average of more developed European countries.

In conclusion, the global results for Chemical Engineering for the period of the report are excellent. The research is of high quality, and the lines of research are constantly being updated –even those which are considered as traditional, such as transport phenomena or heterogeneous catalysis. Nonetheless, maintaining this level of operation may be affected in the future by the personnel problems that were observed during the current period:the insufficient growth in the number of investigators, the difficulty in contracting and stabilizing technical support personnel, and the lack of public resources needed for a better intern/EDP relationship. This consideration comes in the context of a relative standstill in global scientific output in the field during this period.

Scientific output in Textile and Paper Engineering also differed greatly according to the size of its research centers. at INTEXTER, which is fundamentally dedicated to research, the results were better than those of the DETIP. The global results of scientific output in the area were above the Catalan average of theses completed per EDP, while the average number of articles per EDP was similar to the Catalan average and superior to the Spanish averages. These results are very acceptable despite the difficulties in the field during the period of the report, i.e., a decrease in economic and human resources. Still, several research lines such as the development of new fibers as well as textile and paper processes more compatible with the environment should be initiated. It is also recommended that the burden of servicing the sector's industries be transferred from investigators to technicians; this would improve research and technological innovation in the field. The deficiencies observed in Chemical Engineering were also seen in this field and may entail even more serious consequences.

The return of economic resources, evaluated in terms of scientific output, shows that for both fields there is a direct relationship between the size of the center, in number of EDPs, and the return. A better use of economic resources was seen in medium– and large-sized centers, such as the UPC, which, in Chemical Engineering, had the highest output of theses and articles per million Euros, or the DETIP, which despite having a lower output than INTEXTER had better results for these indicators. This leads to the following considerations: there should be some control by administrations of the resources given and their return, in order to correct the disequilibrium and certain deficiencies. Thus, return indexes for research, when allotting human and economic resources, should not be ignored. In addition, the concentration of teams and investigators should be encouraged, as should teamwork in common or related areas.

As a final conclusion it can be said that if the structural deficiencies were corrected and work between groups was supported, facilitating and activating relationships between them, the results obtained in the next period will improve even more. This would not diminish the potential of either field, given their importance to Catalan industry.

Industrial Organization

Characteristics of the Field

There is not a precise definition for the field of Industrial Organization, and in the academic world there are various points of view according to the centers of interest. For this report, Industrial Organization has been considered to comprise all the subjects, concerns, methodologies, and techniques of what is commonly known as Industrial Engineering[1].

1. The name Industrial Engineering was established in Spain in a Royal Decree in 1851. The *Industrial Engineering* is the result of the work of Frederick W. Taylor (1856-1915), Frank B. Gilbreth (1868-1924) and others. The first departments of *industrial engineering* were created in 1908 at Pennsylvania State University and at Syracuse University. The difficulty of literal translation made the activity carry the name of industrial organization as a specialty of industrial engineering in the Study Plan of 1964. The same name was chosen in 1994 for the postgraduate title engineer in industrial organization.

Industrial Organization can be deduced from various manuals[2]. In part, it is linked to a company's productive core, but it also has a strategic aspect. The productive core consists of the design and development of a product and its production process, production itself (including provision, quality control, and maintenance), and the logistics of distribution (the supply chain). The productive systems considered here are related to manufacturing and services, and are also referred to as operations organization or direction of operations.

The strategic components of Industrial Organization include an analysis of competition in the field (industrial economics), product strategies, technology, and industrial management.

University teams working in Industrial Organization

The following discussion is not exhaustive due to the difficulties in delimiting the field of Industrial Organization. Many groups carry out tasks that could be classified as pertaining to Industrial Organization, but as they do not work exclusively in the field. This situation is common in the entire country[3]. In addition, there are groups simultaneously carry out teaching, research and technology transfer through consultancy and advising.

- Technical University of Catalonia. In the Department of Business Organization of the UPC, several groups actively carry out research in Industrial Organization. The Institute of Organization and Control of Industrial Systems of the UPC pursues three research lines, two of which focus on the control of processes and industrial robotics and one of which is devoted to industrial organization. Research in the latter, Organizational Engineering and Industrial Logistics, research is done by a group of professors teaching at the Department of Business Organization. At the UPC's Department of Statistics and Operative Investigation there are groups with similar concerns, particularly in the section Quantitative Techniques Management.
- University of Gerona. A group from the Department of Industrial Engineering (until the year 2002) and from the Department of Organization, Business Management, and Product Design (Department Unit of Business Organization) carry out tasks similar to those of the Department of Business Organization of the UPC.
- University of Barcelona, Autonomous University of Barcelona and Pompeu Fabra University. Several groups carry out research that could be classified as Industrial Organization.
- IESE. There are groups in the Department of Production, Technology, and Operations.
- Ramon Llull University-ESADE. There are groups in the Department of Operations and Innovation.
- CIM Center. Collaborations have been established with different departments of the Technical University of Catalonia. Among other topics, the center works in product and process engineering and the integrated management of production.

Postgraduate Studies

Postgraduate studies are offered under the auspices of the aforementioned groups and from entities oriented towards this type of training, particularly the Technical Foundation of Catalonia, the Catalan Institute for Technology, and Continuous Education of Les Heures.

At the Technical Foundation of Catalonia, there are 17 master degree programs, some with several variants concerning Industrial Organization. The programs are classified in two categories: Engineering and Industrial Technology and Economics and Business Management. The Catalan Institute for Technology has 11 master degree programs in this field, and the Continuous Training of Les Heures has two.

Information Sources

Besides personal contacts, the following networks and documentation were consulted in order to obtain data for this report:

- Report of the Institute of Organization and Control of Industrial Systems (IOC) of the UPC (academic years 1996–1997, 1997–1998, 1998–1999, 1999–2000, 2000–2001, 2001–2002, and 2002–2003)
- Report of the Department of Industrial Engineering of the University of Gerona (academic years of 1998–2000)
- Report of the Department of Business Organization of the UPC (academic years 1996–1997, 1997–1998, 1998–1999, 1999–2000, 2000–2001, 2001–2002, and 2002–2003)
- Report of the Department of Organization, Business Management, and Product Design of the University of Gerona (academic years 2001 and 2002)
- And the following web pages:

www.fpc.upc.es/
www.heures.ub.es/
www.ioc.upc.es/
www.ictonline.es/
www.upf.es/web.postgraus/

Research Groups and Centres

In the report, two groups of investigators in Industrial Organization are considered:

- A consolidated group at the UPC, consisting of the Department of Business Organization of the UPC, the Management Quantitative Techniques Section of the Department of Statistics and Operative Investigation of the UPC, and the research line Organization Engineering and In-

2. For example, H. B. Maynard (1992) *Industrial Engineering Handbook* McGraw-Hill, 4th edition; G. Salvendy *Handbook of Industrial Engineering* Wiley 3rd edition.
3. This situation has favoured the creation of ADINGOR (*Association for the Engineering of Organization*) and the celebration of congresses and conferences (Barcelona 1999; Bilbao 2000; Sevilla 2001; Vigo, 2002; Valladolid, 2003) attended by those who identify their work with industrial organization.

dustrial Logistics of the Institute of Organization and Control of the UPC
- A young, fully developed group at the UdG that was formed by the Business Organization Department Unit of the Department of Organization, Business Management and Product Design of the University of Gerona.

There are three fundamental reasons for choosing these two groups:

- They identify their projects with Industrial Organization, which was not the case in other groups.
- It was feasible to isolate data from these groups from data of the institutions they belong to.
- The data were very informative.

Human Resources[4]
Table 36 presents the data relative to academic personnel for the two groups. Individuals considered to be full-time personnel were separated, since they are usually in charge of the research.

Economic Resources
Financing for research was classified as: European projects, public funds, and private funds. The values shown are the results of estimates and extrapolations. The results (in thousands of euros) for both groups are shown in Table 37.

Results
Theses completed and articles in scientific indexed journals were considered as results. The values, together with the total number of articles –indexed or not– are shown in Table 38.

Indicator or Relative Values[5]
The comparative base was the number of academic personnel with full-time dedication (TC). Financing amounted to an average of 12 408 Euros per person per year, with the annual evolution in Table 39.

This average value is significantly below the corresponding one of either Catalan (21 680 Euros/investigator) or Spanish ,(26 850 Euros/investigator) universities. The comparison is even more unfavorable if we consider the average figure for university and civil centers: 23 170 Euros/investigator in Catalonia and 31 630 Euros/investigator in Spain.

Similarly, the average number of theses completed was 0.14115 per investigator per year and the average number of indexed articles was 0.04573 per investigator per year, as shown together with the annual evolution in Table 40. There is a tendency of stability for theses and a growing one for indexed articles.

The average number of theses per investigator was more than twice the average value of Catalonia, 0.063 theses/investigator per year. However, the number of articles per investigator was significantly lower than the average value of either Catalonia, 0.318 articles/investigator per year, or Spain, 0.274 articles/investigator per year.

If million of Euros of financing is used as the comparative base, the indexes shown in Table 41 are obtained.

The average number of these per million Euros was more than three times higher than the average number for Catalonia, 3.56 theses/million Euros. The number of articles per million Euros was, by contrast, was around a fourth of the average for Catalonia, 13.75 million articles/million Euros, and also significantly lower than the average for Spain, 8.66 articles/million Euros.

Conclusions
Scientific output in Industrial Organization is lower than in other fields regarding the number of articles published in indexed journals. A growing tendency was noticeable in the last few years, which could have been due to demands for this type of publication in the promotion of a university career.

The level of technology transfer, measured based on the funds obtained from private sources, is also important.

One of the main obstacles was the lack of recognition by research institutions that Industrial Organization is an independent activity. This was confirmed by the fact that many investigators working in this area, in order to be notified about financing for research projects, have to classify their proposals as pertaining to economics or automatics.

Concluding remarks and recommendations

Research in Industrial Engineering in Catalonia involved an average of 564 investigators (with the equivalence of 1 professor working TC = 1 EDP) and an average expenditure of 8.82 million Euros, without taking into account the cost of the university staff or resources obtained for training activities.

Calculation of the number of investigators for Energy and Electric Engineering and Mechanical and Materials Engineering was restricted to the UPC. For Chemical, Textile and Paper Engineering, and Industrial Organization, it was possible to include data from other university groups.

Some 65% of research staff and 62% of expenditures could be attributed to the UPC. Figures 33 and 34 show the distribution of these two resources in the four fields covered by this report.

The considerations and conclusions presented in the analysis of each of the fields show the variability of the research conditions in Industrial Engineering.

In order to provide an overview of the entire dataset and facilitate a comparison between the fields analyzed, Figs. 35–39 present the information relative to the studied indicators for all of Industrial Engineering and for a subset of this field:

- Average annual expenditure (in thousands of Euros) per investigator
- Average annual theses per investigator

4. Both the UPC and the UdG groups are a subset of those considered in the *Report of Research in Economics in Catalonia (1996-2002)*.
5. It should be taken into account that we had at our disposal 7 years of data for the UPC group and 3 for the UdG group

Table 36. Human resources

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
UPC group								
Academic personnel	132	125	136	135	150	164	187	147
TC	59	60	60	60	62	73	80	64.86
UdG group								
Academic personnel	nd	nd	25	29	29	36	39	31.60
TC	nd	nd	13	14	16	16	17	15.20

nd: Data not available

Table 37. Research financing

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
UPC group								
European projects	69.5	471.9	397.1	502.2	79.6	178.6	274.4	281.9
Public funds	85.8	226.7	103.6	276.2	828.1	282.4	579.6	340.3
Private funds	305.7	251.6	220.5	201.3	150.7	257.3	185.5	224.7
Total	461.0	950.2	721.2	979.7	1058.4	718.3	1039.5	846.9
UdG group								
European projects	Nd	nd	nd	nd	0	0	0	0
Public funds	Nd	nd	nd	nd	52.3	68.2	11.4	44.0
Private funds	Nd	nd	nd	nd	2.6	70.6	110.6	60.4
Total	Nd	nd	nd	nd	54.9	138.8	122.0	104.4

nd: Data not available

Table 38. Theses and articles

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
UPC group								
Theses	4	10	9	11	14	8	9	9.29
Articles	14	10	13	24	26	25	19	18.71
Indexed j.	4	1	1	2	2	5	7	3.14
UdG group								
Theses	nd	nd	nd	nd	1	3	2	2
Articles	nd	nd	nd	nd	8	5	13	8.67
Indexed journal	nd	nd	nd	nd	0	0	1	0.33

nd: Data not available

Table 39. Financing per TC investigator (in thousands of Euros per person).

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
Financing per TC investigator	7.81	15.84	12.02	16.33	14.24	9.63	11.97	12.41

Table 40. These and articles per TC investigator

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
Theses per TC investigator	0.068	0.167	0.150	0.183	0.192	0.124	0.113	0.141
Indexed articles per TC investigator	0.068	0.017	0.017	0.033	0.026	0.056	0.082	0.046

Table 41. Theses and articles per million Euros of financing

Year	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*Annual average*
Theses per million Euros	8.68	10.52	12.48	11.23	13.50	12.83	9.47	11.38
Indexed articles per million Euros	8.68	1.05	1.39	2.04	1.80	5.83	6.89	3.69

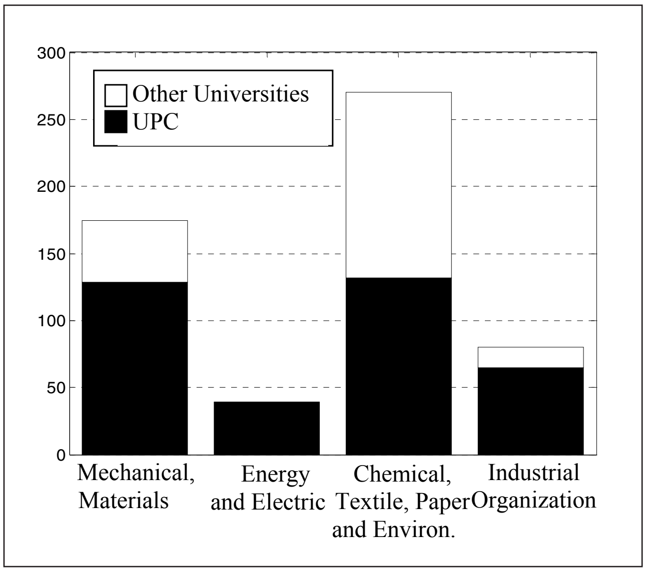

Figure 33. Annual average number of investigators in the four fields comprising Industrial Engineering.

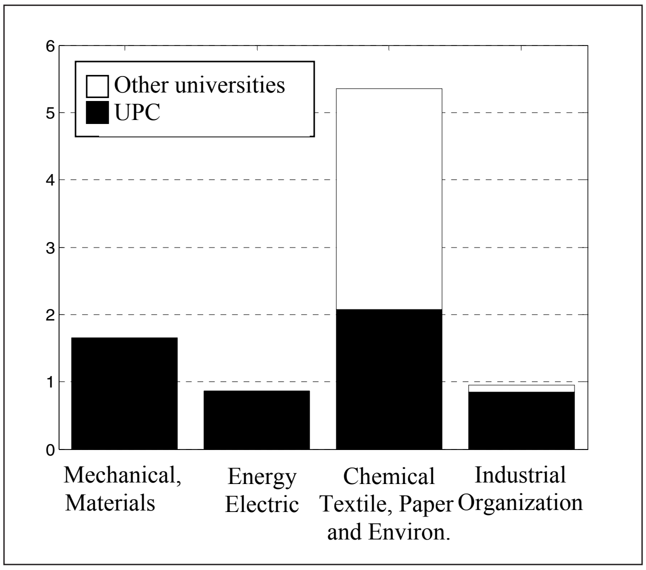

Figure 34. Expenditure on research (in millions of Euros) in the four fields studied in the report.

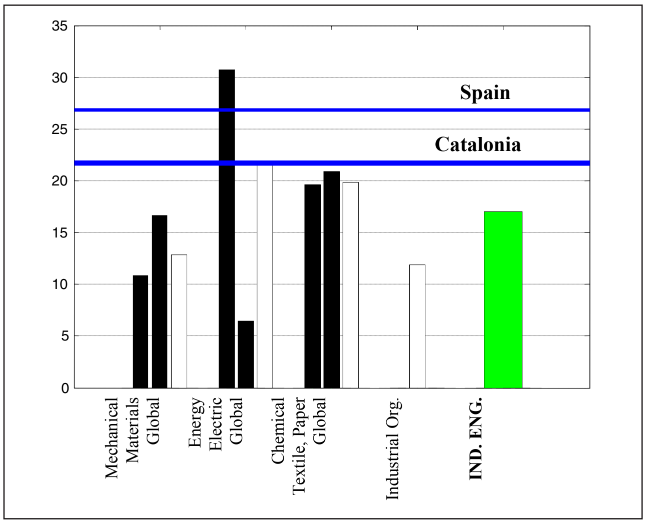

Figure 35. Average annual expenditure per researcher (in thousands of Euros) for the most-recent study period. Green column indicates value for Industrial Engineering as a whole.

– Average number of theses per million Euros of expenditure in research
– Annual average number of indexed articles per investigator
– Average number of indexed articles per million Euros of expenditure in research

In Figs. 35–9, the values for Mechanical and Materials Engineering and Electrical and Energy Engineering are restricted to the UPC. For the latter field, the Department of Physics and Nuclear Engineering was excluded because the inclusion of Physics would have affected the results.

These figures show that, globally, the output for Industrial Engineering, despite a level of financing per investigator that is 78% of the average for Catalonia (in universities) and 63% of the average for Spain, is greater than that of Catalonia or Spain. The annual average of theses per investigator and the average number of theses per million Euros were twice those of Catalonia. The indicators were particularly high for the De-

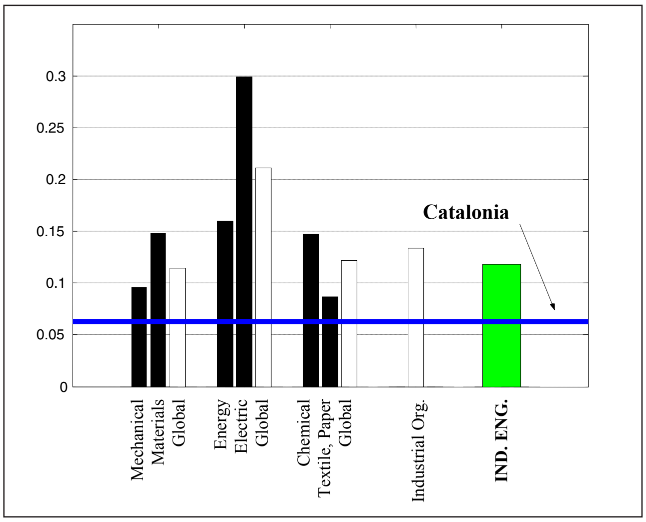

Figure 36. Average annual number of theses per researcher for the most recent study period. Green column indicates value for Industrial Engineering as a whole.

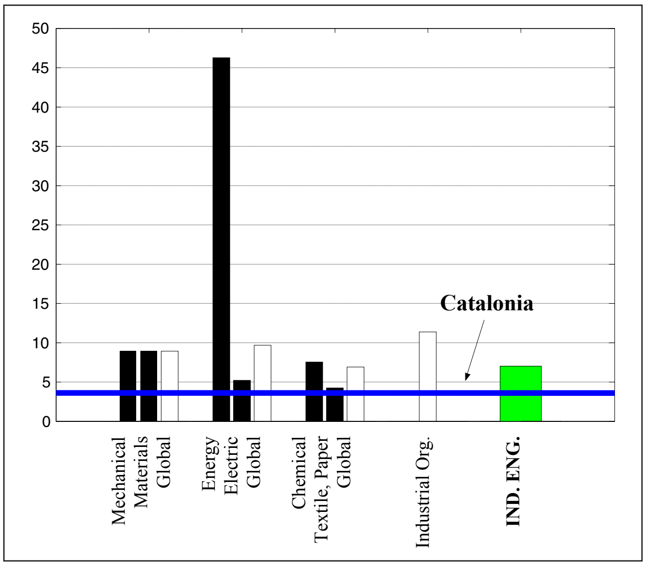

Figure 37. Average number of theses per million Euros of expenditure. Green column indicates value for Industrial Engineering as a whole.

partment of Electrical Engineering, due to a small number of investigators and limited financing, and the motivation for the development of theses by its large professoriate. It is therefore a group in transition –strengthening its research activities; hence, its research indicators were atypical. The annual average number of indexed articles per investigator surpassed by 33% the average for Catalonia (and by 54% that for Spain. The average per million Euros was 2.4 times greater than that of Catalonia and 3.8 times greater than that of Spain.

This globally positive evaluation was partially obscured by the great difference between research groups with respect to investigation, as seen in Figs. 33–37 and even more in the detailed analysis for each of the four subfields. An evaluation of the causes of this situation and of the factors that intervene allowed us to reach some conclusions and to propose several recommendations aimed at improving the management of research by public institutions in order to consolidate the strong points and correct the weak ones.

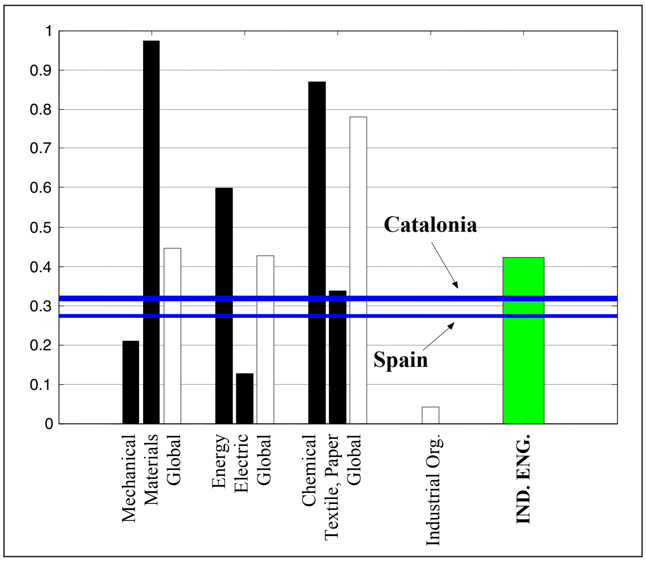

Figure 38. Average annual number of indexed articles per researcher. Green column indicates value for Industrial Engineering as a whole.

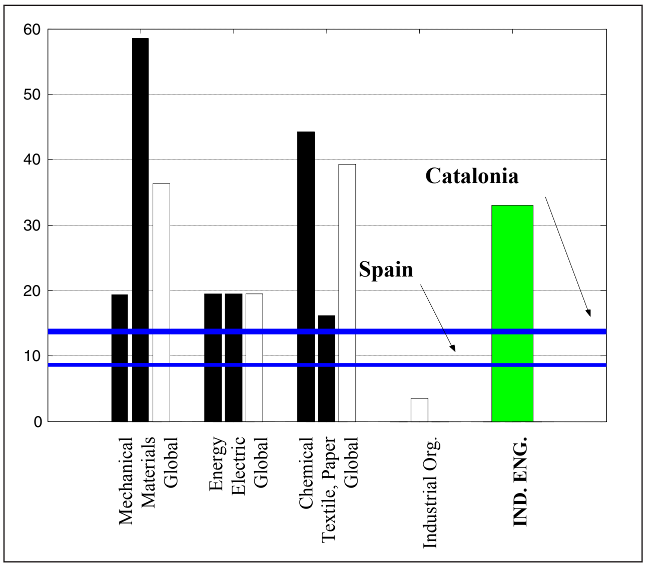

Figure 39. Average number of indexed articles per million Euros of expenditure. Green column indicates value for Industrial Engineering as a whole.

The most worrisome aspect of those groups with a low research output is none other than the main protagonist of research: the investigator. In the Catalan university environment, investigators are personnel who should be in charge of teaching and research activities, although the latter does not seem to be appropriately demanded.

An analysis of those groups with the highest output reveals the external factors that make success possible and to identify the factors that limit research, such as a deficiency in support personnel and an inadequate platform between universities and the industrial sector and those institutions –Catalan, Spanish and European– that promote research.

What follows are the most relevant final considerations.

– Lack of requirements demanded for research activities of professoriate working full-time at a university. There is a complete tolerance of full-time professors who do not carry out research or who participate in agreements that do not translate into indicators of research output (theses and articles). Full-time dedication is granted and renewed without any requirements relative to these indicators.

  As shown in various sections of this report, groups or centers with a high level of research activity –with output indicators comparable to centers of international prestige– coexist in the same field with others that simply do not carry out research but instead offer specialized services –assays, verifications, homologations, studies, etc.– and technical projects for the industrial sector.

  Another event that illustrates a lack of requirements by the university is the existence of numerous lines of research that did not result in the publication of indexed articles during the period of the report, or for which the number of articles per investigator was significantly below the corresponding one in Catalonia. This was, for example, the case in Mechanical Engineering.

  Economic incentives from the Ministry –for periods of six years– are not sufficient for a professor with no career goals to research and produce results. Furthermore, from the economic point of view, the withholding of these incentives can be easily compensated for by gains from agreements.

  The solution to this problem would be a requirement by the university that a professor complete a minimum of research output in order to have his or her full-time position renewed. It would also help if research activity received more incentives, although not necessarily economic ones. Greater availability of interns and support personnel would be an appreciated recognition for investigators or groups that excelled in the indicators of research output.

– Influence of group size. The size of a group is not decisive for the quality or quantity of research activity. Nonetheless, it has been observed that large research groups are more efficient than smaller groups in the same field. With a smaller expenditure/investigator, higher indicators of production –articles and theses per investigator and articles and theses per million Euros of expenditure– are obtained by larger groups. The greater diversity of people and diverse topics of investigation create favorable synergies. Moreover, these groups are more stable because they guarantee a critical mass that, in turn, improves the working conditions of those who become part of it.

A large group without research goals is also stable, but in a way that harms its investigations. The selection of new personnel and collective decision-making are usually carried out in a way that perpetuates the non-investigative majority. Mechanical Engineering is an illustrative example of this, since in the previous report (1990–1995) this field was pointed out as being hardly productive, a situation that did not change during the period of this report. Mechanical Engineering is comparable in size to the Department of Materials Science and Metallurgy, one of the groups of excellence in both this and the previous report. In a small group, the entry of a single person with leadership capacity can mean a radical change towards research excellence. In a large group with a vast non-investigative majority, this change is not possible.

Large groups –often university departments– can integrate a good number of specific research centers that facilitate the formation of links between research and emerging topics. The efficient performance of these centers is guaranteed by those groups supporting them. The Department of Chemical Engineering of the UPC is a good example. By contrast, specific centers created without a powerful base are usually sterile with respect to research output, although this report also found small groups of great productivity, such as ECoMMFiT of the URV.

Thus, the establishment of large groups with research goals should be promoted, as should the creation of specific groups within these larger ones that are able to respond to emerging topics.

A step that goes beyond the size of the group is the internal relationships of the groups, the different disciplines with research goals, in "research centers without walls". Their multidisciplinary character, together with the great number and variety of investigators, promotes the research capacity of the member groups by enabling them to participate in larger and more complex projects. The CeRTAP (Reference Center in Advanced Production Techniques), which integrates research groups in different fields, is a good example of these centers without walls.

– Research support personnel. The insufficiency of technical support personnel for research is an endemic problem in Catalonia and Spain. The figures for the number of support technicians per investigator for some of the groups of Chemical Engineering and Textile and Paper Engineering at the UPC were between 0.02 and 0.07, which are well below the average of 0.4 common in Germany, France, and the UK.

Research support personnel that is stable and adequate in number is a decisive factor in the structure of human resources for research. It is inefficient that their tasks are frequently carried out by investigators. Since the specific training needed to adapt support personnel to the workplace represents a large investment for the team that receives them, their stability is essential. The current rules do not resolve either aspect. The practice that after 3 years support personnel have to leave the research team, rules out stability and the incentive to hire adequate numbers of such personnel.

The hiring of support technicians in substantially greater numbers should be promoted, and conditions should promote the stability of such personnel within the group. This number of personnel should be correlated with the research group's results, as evaluated through adequate indicators.

– Intermediary organizations between university and administration. Obtaining European or state-supported research projects is very important for research groups and for Catalonia, but the difficulties and the effort required for the process of application become an obstacle rarely overcome by many groups. Even for large groups, the time and effort needed to prepare the proposals can represent an important fraction of their management capacity.

Institutional support would help to channel the arrival of European and state aid to groups of research excellence. An area in which this intervention would be particularly efficient is Energy Engineering, due to its strategic character. This is one of the actions foreseen in the Energy Plan for Catalonia on the Horizon of the Year 2010, elaborated in 2002 by the Department of Industry, Commerce, and Tourism of the Government of Catalonia, which is currently under revision. The creation of an office that connects Catalan research groups –mainly university-based– with financing institutions in the different fields of engineering would facilitate the interaction of these groups and their participation in wider and more interdisciplinary projects than is currently the case.

– Agreements and research. The agreements of university research groups with the industrial sector are the most predictable channel for technology transfer and for the participation of investigators in technological innovation. Moreover, such agreements are an important source of economic resources for the maintenance of both research infrastructure and the costs of human resources. There are, nonetheless, two aspects that should be improved. First, so-called Technology Transfer Centers should not limit themselves to the economic management of agreements. They should also have experts in the selling of research who act as a link between university research groups and the industrial sector. This is an inappropriate activity for research groups, not only because of their insufficient size to allocate personnel to this tasks, but also because negotiators with the industrial sector should have a wide vision of the possibilities of research offered by the university for all its fields.

Second, there is the research component of agreements. Often, and in particular for university groups with low research output according to the indicators used, the agreements correspond to specialized services and technical projects. Currently, the CTT of the UPC distinguishes between services and agreements according to their cost. The cost of services cannot exceed 6000 Euros annually, and it is recommended that agreements that pass as services are of a value less than that. This criterion based on cost should be substituted by one based on content. Agreements would correspond to research activities arranged by contracts with businesses, while services would correspond to specialized technical services –including technical projects. It should be noted that in undertaking specialized services and technical projects there will be competition with engineering companies and assay laboratories. Thus, it makes sense to act in this area when the university, due to its human and instrumental resources and its location, is in a better position to carry out services otherwise done by non-university engineering or assay laboratories. The justification for providing specialized services and technical projects should never be the possibility of offering them at a lower price because the cost of personnel and infrastructure are covered by the university; that would be unfair competition.

Regarding this point, the intervention of AIDIT should be mandatory –accrediting projects appropriate for university-company agreements (of research) and deciding which activities which should be considered as services.

- Adaptation of research promoting institutional programs. In general, it cannot be considered that the low level of research output by some groups is due to research-promoting institutional programs. These programs have allowed the consolidation of efficient research groups, and in many fields their priorities are broad enough that any research group could adapt, reorienting itself if needed, their specialization. Energy Engineering is a field in which more substantial changes are needed with respect to the institutional promotion of research, so that the participation of universities –and particularly Catalan universities– is more intense. Such changes would be favored by the aforementioned creation of an office linking research groups and administrations.
- Circulation of information on research. The elaboration of the present report was immensely difficult due to the lack of data related to research in some universities. Among the universities consulted, only the UB and the URV have reasonably complete and consistent databases. As for the UPC, whose database was the most frequently consulted, the inconsistency of its research databases –where for the same piece of data, different results were found according to the access route– was a particular obstacle. It was overcome thanks to direct support by personnel from the central services involved. While such problems may not be a decisive aspect of research in a country, they do reflect to some extent its research structure and the accessibility of information. The availability of information increases transparency and gives a precise picture of what is done and by whom.

Summing up these considerations, we can state that research in Industrial Engineering in Catalonia is in a relatively strong position, but the quality of its groups differs greatly. Groups of excellence have continued to improve their indicators since the last report but those of low output have maintained their low level. The proposals for improvement are primarily aimed at guaranteeing the research component of the activities of full-time university professoriate. From this inalienable measure onwards, research would be favored by an increase in human resources (support personnel) and their stabilization, through the creation of a platform between university research groups and institutions that promote research. This step could be taken by Technology Transfer Centers –which would act as research sales agents– and the AIDIT to guarantee that agreements indeed correspond to activities in research.

It would also be convenient to increase the size of groups that excel in research, and to target support to specific centers able to respond to emerging topics.