Evaluation of research in engineering science in Norway

Report of the Principal Evaluation Committee

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To the Research Council of Norway

The members of the Principal Evaluation Committee for the evaluation of research in engineering science in Norway submit this report, based on the general conclusions and recommendations of the three evaluation panels: Panel 1: Construction Engineering, Production and Operation, Panel 2: Structures, Materials, Product Development and Design, and Panel 3: Energy and Process Technology.

The views expressed in this report are consensus views of the Committee. The members of the Committee, having deliberated the separate panel evaluations, are in collective agreement with the assessments, conclusions and recommendations presented.

July 28, 2004

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Executive summary

The objective of this evaluation is to assess the quality and relevance of the research in engineering science in the Norwegian universities and university colleges. The conclusions lead to a set of recommendations for the institutions concerned, for the Research Council of Norway (RCN) and for the relevant Ministries, for industry and for society at large concerning the future development of research in engineering science in Norway.

The mandate states a requirement for an evaluation of research in engineering science. However, a clarifying discussion with the Research Council revealed that what was required was an evaluation of research in engineering and that the title Engineering Science was a consequence of process of translation from Norwegian to English. Thus the evaluation presented here considers engineering research in the round.

Engineering sometimes advances by heuristic methods based on trial and error and data reduction when the underpinning science is unclear or too complicated for the deductive analytic approach of engineering science. Engineering research therefore includes both of these approaches to the acquisition of new knowledge.

The Principal Evaluation Committee (PEC) starts from the observation that the engineer of the 21st century should have a broader vision on the world and its problems than his/her 19th century colleague. Where the latter was a creator of only-hardware artefacts, using rudimentary design tools, the contemporary engineer, equipped with a wealth of hardware and software tools, with a nose for the large contemporary societal problems, creates complex, multi-technology artefacts, consisting of mixed hard/software systems.

The PEC observed that the present research agenda of the four evaluated institutions (Norwegian University of Science and Technology (NTNU), Agricultural University of Norway (AUN), Narvik University College (NUC) and Stavanger University College (SUC)) mainly covers the so-called traditional disciplines and follows hereby a traditional, predominantly mono-disciplinary approach. There is an imbalance in favour of project-driven, directly applicable (short-term) research. The basic research component is underdeveloped. However, it cannot be denied that this approach has probably contributed significantly to the present wealth of Norway.

To ensure that Norway maintains an internationally leading position in those areas of engineering important to the national economy the Research Council should carefully consider whether adequate support is being given to new research areas, now missing from the research agenda, such as mechatronics, precision engineering, microsystems technology and nanotechnology. Actions to stimulate collaborative, interdisciplinary research including these areas should be started.

The Principal Evaluation Committee recommends that:

- strategic research plans be established at all levels, reflecting the needs of the target groups, according to a top-down/bottom-up/meet-in-the-middle iterative process. Appropriate follow-up mechanisms should be put in place to guarantee the effectiveness of those plans.

- effective leadership be stimulated in the research groups, in order to ensure a more effective implementation of the formulated strategies, by considering appointment rather than election of department heads, by providing training in management to the research staff, and incentives for management functions.

- investment be made in the development of those research groups that are considered to be strategic for the future development of Norway. These might include: energy systems, oil and gas extraction technology, manufacturing, product design, product development, engineering design, operations management, materials engineering.

- prompt action be taken to increase the publication by research groups of papers in recognised archival journals.

- to prevent deterioration of the competitive position of Norway, particularly in the manufacturing sector, new research areas, now almost missing in the research agenda of engineering faculties, such as mechatronics, precision engineering, microsystems technology, nanotechnology, should be urgently considered. Activities in collaborative, interdisciplinary research should be started.

- stimuli be applied to increase the level of basic research in engineering science:
  - RCN can contribute by substantially increasing the funding level of engineering research, by creating special programmes that foster cross-disciplinary and cross-institutional research,

  - The universities can contribute by allocating part of their own funds for basic research governed by a "University Research Council"; by levying overhead on involvement of university researchers in applied research projects, e.g. via SINTEF, to support basic research; by providing different categories of funding, e.g. grants to promising young researchers, interdisciplinary research,…

  - A better organised PhD education system should be established at the universities,

  - A multi-criterion rating system for engineering research should be developed and applied within which peer-reviewed international journal publications are an important category.

  - The position of education and research in engineering in Norway should be strengthened by:
    - enhancing international presence and connectivity by recruiting international faculty for both long and short term employment,
    - taking actions to counter the waning interest in engineering among the youth,
    - taking measures to enhance the recruitment process of academic staff and PhD students,
    - taking actions to address the gender imbalance in engineering academia.

- Entrepreneurship among the research community be stimulated. The existing initiatives to stimulate innovation (e.g. Leiv Eriksson Nyfotek, Gløshaugen at NTNU) should be advertised more actively to the researchers.

- The ambiguities with respect to the research policy of the regional colleges be resolved by clear signals from the government and from RCN.

More details about these recommendations are given in the report.

The new role of engineering and engineering science

About engineering, and engineering science

One of the earliest definitions of engineering, in the 1828 charter of the British Institution of Civil Engineers, asserts that engineering is "the art of directing the great sources of power in nature for the use and convenience of man." That definition is still valid although only in part. The great sources of power –fire, wind and falling water, augmented in the latter half of the 20th century by nuclear fission- are being used by engineers today, as they were in 1828, to change the world for the use and convenience of humankind. But engineers are also the ones who design important artefacts such as bridges, highways, automobiles, aeroplanes, ships, offshore platforms, telecommunication systems, water systems, heating and air conditioning systems, computers, television networks, medical systems and alternative energy generators, things that influence strongly and directly the way we live from day to day. The great challenges of our society –energy, environment, mobility, health and food production are to a large extent challenges to the engineers and scientists of the future. Moreover, enormous opportunities are offered to the engineers by the technological revolutions that are in progress in microelectronics, information and communication technologies, micro- and nanotechnology and biotechnology.
When one realizes that engineers make up a mere one percent of the population in the US and Europe, then they are a potentially influential group, who also have an enormous responsibility towards that same society.

Natural science versus engineering (science)

Because of its distinct nature, engineering science is called 'the sciences of the artificial' by Herbert Simon [1]. Simon states that "the central task of natural science is to show that complexity, correctly viewed, is only a mask for simplicity, to find patterns hidden in apparent chaos".

The world we live in today is increasingly a man-made or artificial (synthesized) world. This synthesized world of artefacts is the world of engineering (science). An important distinctive feature of several engineering disciplines is the aspect of design. Design aims at finding the optimal solution to an engineering problem out of an infinite multitude of possible solutions. Comprehensive design theories do not exist, particularly in the conceptual or creative phase of the design process.

It is the strong opinion of the Principal Evaluation Committee (PEC) that there is a need for more basic research in engineering science but not to the detriment of engineering research. Or stated in terms of the excellent document: 'Measuring

[1] Herbert Simon, '*The Sciences of the Artificial'*, The MIT Press, Cambridge, MA, 1981.

excellence in Engineering Research' [2], Mode-2 research should live alongside Mode-1 research. These considerations should be borne in mind when establishing a publication policy for engineering research. The publication customs of the natural science community should not be slavishly adopted but rather adapted to the unique character of engineering (research).

The scope of research in engineering

Research in Norway is mainly funded by government agencies and industry. It may therefore seem normal that the results of the research flow back to the society generating the funds. This may explain in part why a sizeable amount of the present publication output of many of the evaluated research groups is of particular relevance to the public sector and Norwegian industry, except for a few internationally orientated research fields such as, for example, petroleum engineering.

As has been discussed above, the engineering environment is increasingly becoming globalised, influenced as it is by the ICT revolution and changes in investment practices. Consequently, research in engineering is bound to become international too. Moreover, it is best carried out at all levels simultaneously: basic research, problem driven and application driven, as one level fertilizes the other. Without intensive basic research in engineering science the development of engineering as a discipline will be unbalanced and key new innovations may be missed.

International publications have been markedly under par in virtually all engineering disciplines visited by the three Panels. The only way to know about the intrinsic value of one's own research is to have it scrutinized by peers on an international level, through publications in international, peer-reviewed journals. The RCN and the universities themselves can do a great deal to promote this through creation of special funding categories, as explained further below.

Engineering is multi-disciplinary

Engineering is evolving from a set of rather distinct disciplines (civil, thermal, electrical engineering) into a truly multi- and inter-disciplinary activity. Besides the traditional enabling engineering disciplines such as strength of materials, structures, fluid mechanics and thermodynamics, concurrent engineering or simultaneous engineering is the best current approach to cope with the complexity of the artefacts and systems of the modern technological world. Mechatronics is one good example of such an integrative approach where machine design (mechanical engineering), microelectronics, control engineering and informatics are synergistically combined during the design of complex artefacts (e.g. automobiles).

The engineering curricula and research programmes should take into account this evolution in their development towards a holistic view of engineering science.

[2] Royal Academy of Engineering, *'Measuring Excellence in Engineering Research'*, London, 10 January, 2000.

Engineers and engineering scientists should be educated with this integrative view in mind in order to be able to come up with the innovative solutions required for their country to be competitive. Japan has conquered the consumer electronics and many other markets with techniques based on the Mechatronics paradigm. They have the integrative reflex built-in to their harmony model of society.

Information and communication technology, the key to modern engineering

Where in the traditional view a factory was a place where raw material, energy and information were transformed into finished products, waste and waste energy, in the post-modern version, a factory is a place were information is transformed into finished products by the controlled supply of raw materials and energy. Knowledge and information have become the most important production factors, next to the traditional ones: capital, capital goods and people. Engineering is becoming the art of transformation of information into prosperity. The traditional engineering disciplines will have to recognise this trend and integrate ICT into the engineering curricula and the research programmes.

The availability of software tools is having a profound effect on the prevailing design and research methods in engineering. The use of scale models and prototypes is being gradually replaced by so-called ‘virtual engineering’ tools. Simulation takes over from physical model building, except in designing complex dynamic systems where physical modelling remains essential to gain physical understanding.

ICT has enabled the transformation of the manufacturing industry from rigid megafactories to agile virtual enterprises consisting of flotillas of small companies, distributed all over the world. This paradigm shift gives rise to completely new ways of design and engineering practices (collaborative engineering), product description (product models), exchange of data (workgroup computing, STEP, …). Modern aeroplanes are good examples of simultaneously engineered artefacts, where systematic use is being made of the modern virtual engineering tools, by virtual enterprises consisting of many hundreds of companies spread over the world.

This revolutionary penetration of ICT into design, engineering, manufacturing methods and the complete supply chain will have a profound effect on the organisation and content of both future research labs of technical institutes and on the structure of future engineering curricula.

The ‘civic’ engineer

The major problems facing our society are in fact not scientific or technical problems but human ones: an aging population in a post-industrial society, the alienation of people in the cities, health problems, appropriate shelter and enough food and energy for everybody, etc. Scientists and engineers cannot be expected to solve these vast problems alone or from within their own safe professional communities. Engineers must learn to play a new, additional role in society, that of the ‘civic engineer’, or ‘civilized engineer’ as Florman stated it [3]. In this new capacity, engineers would step beyond their campuses, laboratories and institutes and into the centre of their communities to engage in active dialogue - a two-way conversation - with their fellow citizens. Training for that role should become an integral part of any engineering education, and research programmes should also include societal considerations.

The engineer-entrepreneur

A balanced portfolio of research in engineering should not serve the sole purpose of advancing the state of the art, but also of further developing the research results into products for the benefit of society. Engineering schools should not become business schools but the engineering curricula should contain training in management skills and entrepreneurship. Already in 1939, Schumpeter stated that creative entrepreneurship is the basic requirement for a society to move ahead. There are many good examples to demonstrate that a sense of entrepreneurship in an engineering research lab is not contradictory to high-quality research; on the contrary, they often go hand-in-hand.

When reading the recommendations

This joint report has been written with the above thoughts on the evolution of the technological society and with the requirements placed on the contemporary engineer and engineering research, in mind. When reading the recommendations made hereunder, the reader is asked to take into account the considerations made above.

[3] S.C. Florman, *Civilized Engineer*, St. Martin's Press,1987.

State of research and recommendations for future development

Introduction

The objective of this evaluation is to assess the quality and relevance of research in engineering in Norwegian universities and university colleges. The conclusions should lead to a set of recommendations concerning the future development of engineering research in Norway.

The evaluation is expected to give a basis for:
- The institutions concerned, at different levels of their organization, for further development of their research activities
- Strategic decision making by the RCN, determining future priorities within and between individual areas of research
- Identifying areas of research that need to be strengthened in order to ensure that Norway in the future will possess necessary competence in areas of importance for the nation.
- Providing advice to relevant ministries funding research in engineering

Three evaluation panels have been established for major sub fields within engineering science. The Principal Evaluation Committee (PEC) has six members, the chairman and an additional member from each of the three Panels. This Principal Report is based on the general findings and recommendations of the three Panels.

The PEC realises that Norway is a fortunate country with very large human and economical resources. It also has noted that the resources allocated for engineering research and development are less than might be expected in view of this wealth.

International position of Norwegian research in engineering

International status of the research teams

Understandably, the strong research teams are mainly located at NTNU. Evaluation of 33 research groups at NTNU, by the three Panels, resulted in an overall average score of 3.58, which is markedly better than 'good'. Eleven groups obtained a rating better than 'very good', and six groups achieved an overall 'excellent' or close to excellent. These six groups are:
- Physical Metallurgy (Department of Materials Technology)
- Hydraulic Engineering (Department of Hydraulic and Environmental engineering)
- The RAMS group (Reliability, Availability, Maintainability and Safety) (Department of Production and Quality Engineering)
- Waste and Wastewater Engineering (Department of Hydraulic and Environmental Engineering)
- Marine Structures (Department of Marine Technology)
- Operations management (Department of Production and Quality Engineering)

Still better than very good are:

- Steel and Light Materials (Department of Structural Engineering),
- Thermal Energy, Industrial Process Technology and Fluids Engineering (Department of Energy and Process Engineering),
- Petroleum Engineering (Department of Petroleum Engineering and Applied Geophysics)

The Department of Energy and Process Engineering stands out because of its uniform high ratings throughout its four research groups.

The other evaluated institutions (Agricultural University of Norway (AUN), Narvik University College (NUC) and Stavanger University College (SUC)) have no research groups with overall ratings better than 'very good'. Close to 'very good' was found to be Aquaculture Engineering (Department of Agricultural Engineering) at AUN.

At the other end of the spectrum, there are no groups at NTNU with an overall rating 'fair' or 'weak'. Slightly less than 'good' are:

- Geomatics and Construction Engineering (Department of Civil and Transport Engineering)
- Solid Waste Engineering and Recycling (Department of Hydraulic and Environmental Engineering)
- Manufacturing of Metals and Structural Integrity (Department of Engineering Design and Materials)
- Product Design (Department of Product Design)

At AUN, the groups Building Technology and Architecture (Department of Agricultural Engineering) and the Department of Mapping Science, as well as the Mechanical Engineering group (Department of Mechanical Engineering and Material Science) at SUC got a rating 'fair'. Finally, at NUC, the Electromechanical Systems group (Department for Computer Science, Power and Space Technology) got an overall 'weak'.

The ratings at NUC and SUC have to be seen in the light of the special circumstances in which the researchers in those institutes have to work. Both institutes are young, without a long research tradition. The research groups are further small and hence sub critical. The largest obstacle however is the fact that these two institutions are not or have just recently been entitled to award PhD degrees. SUC seems on the verge of being awarded the university status. A clearer policy vis-à-vis these colleges from the side of the Norwegian government is required to clear up the ambiguous situation the research groups are in now. See further recommendations under section Regional Policy.

International relevance of the research topics

The research topics covered by the departments assessed by the Panels cover many of the contemporary engineering problems that are relevant or strategic for Norway: civil and transport engineering, hydraulic and environmental engineering, structural engineering, marine technology, materials, engineering design, production and quality engineering, energy and process engineering, petroleum engineering, electrical power

engineering, architectural design, agricultural engineering. These disciplines should be further supported and developed to continue to educate up-to-date engineers and to further the state of the art by high-level research, to safeguard and renew the Norwegian industrial and public infrastructure, the manufacturing industry and, above all, to continue to excel in fields where Norway has been traditionally strong.
For research to be able to contribute to the competitiveness of Norwegian industry it has to be excellent also when measured on an international scale. Indeed, contemporary trends in society (globalisation, deregulation, and privatisation) allow companies to select the best research environments, wherever they may be located in the world. E.g. Norsk Hydro could consider moving their structural engineering research to a German university rather than collaborate with NTNU when it turns out to be more rewarding.

An internationally strong position can only be maintained by competing with peers on a worldwide basis. One important element to achieve this is by publication in international peer-reviewed scientific (engineering) journals. Only a few research groups have adequate publication rates at the international level. It is recommended that prompt action be taken to improve the situation.

Increasing the efficiency of the research groups

It has been observed by the Panels that some groups work isolated from others that are active in more-or-less closely related research fields, within the same university or in different colleges or universities. Although competition among groups can be stimulating and beneficial for the research quality, it is the opinion of the PEC that the following groups could benefit from closer contacts:

- Geomatics at NTNU and AUN
- Product Development, Product Design, Production Systems at NTNU and Machinery and Biosystems Engineering at AUN
- Petroleum Engineering at NTNU and Petroleum Technology at SUC
- Marine Systems (aquaculture group) at NTNU and Aquaculture Engineering at AUN
- Marine Structures and Marine Civil Engineering at NTNU

Ways to achieve this are:

- Establishment of 'virtual' research institutes, locally or in an international context. European Networks of Excellence are good examples of the latter.
- Creation by RCN of special research programmes that require interdepartmental/interuniversity research co-operation. Examples of such programmes are the SFB (Sonderforschungsbereich)-programmes in Germany awarded by DFG, the IAP (Interuniversity Attraction Poles)- programme in Belgium.

Which fields are missing or under-represented?

It was observed by the PEC that the present research agenda of the four evaluated institutions covers the (more or less) traditional disciplines and follows hereby a rather traditional, mono-disciplinary approach. In view of the analysis made in the preamble there is a need to incorporate the potential offered by the new emerging disciplines (e.g. ICT), but also to embark on new technologies. The PEC identified following research areas that are presently missing in the research agendas:

- Resilience, a cross-disciplinary topic of national importance (including risk assessment, environmental impact assessment, disasters, management and communication aspects of inter-service co-operation)
- Mechatronics (sensors, control, automation, robotics) as an integrating new paradigm for concurrent engineering
- (Engineering aspects of) nanotechnology, nanomachines, nanorobotics
- Microelectromechanical systems (MEMS)
- Biomechanics/Medical instrumentation technology
- Design theory, systems engineering

Balance

All three panel evaluation reports found that there is an imbalance in favour of project-driven, directly applicable (short-term) research. The basic research component is underdeveloped in most research groups. This situation has prevailed for some time and probably has contributed significantly to the present wealth of Norway, particularly in the strategic areas of the Norwegian economy: petroleum, maritime, and fishery industries.

However, if this continues the competitive position of Norway will probably decline. This would particularly be the case in the manufacturing sector. If Norway is to remain competitive in this sector it needs to increase its productivity in manufacturing and develop a range of innovative products. In this case, special care is needed for research groups such as Materials Engineering, Manufacturing, Product Development, Product Design, Production Systems, Operations Management, Engineering Design. New research areas, now missing from the research agenda should also be reviewed to see whether they are important for Norwegian industry. Examples include: mechatronics, precision engineering, microsystems technology (MST) and nanotechnology. Collaboration should be set up with the Departments where these technologies have already been introduced.

To bring the research landscape into balance, funding in basic research in engineering will need to be substantially increased. The RCN should realize that research in engineering is generally different from research in natural sciences. Special programmes could be set up that stimulate cross-disciplinary/cross-department/cross-institution collaboration. NTNU could implement its own research policy by establishing an “NTNU Research Council” that allocates, on a very selective peer-review basis, a special research fund. Such a fund would allow the departments to have their own (basic) research policy, independent from SINTEF. See recommendations.

Inter-/multidisciplinary activities

As stated above, not only should new fields of research be considered, but, if initiated, these should be merged and integrated into the existing research portfolio. A good example is nanotechnology. Where the materials aspects of nanotechnology belong rather to the research groups in natural sciences, the engineering aspects of it - meaning the intelligent use of these materials in innovative new products - should belong to the research of departments of materials of engineering faculties. Another example is mechatronics. By the intelligent integration of machine design, control engineering, physics (e.g. optics) and informatics, products with superior performance can emerge. A third example is the digital factory. ICT has revolutionized the manufacturing sector. Thanks to this revolution, time to market for complex products has been drastically reduced and manufacturing productivity markedly increased. The PEC has the strong impression that inter- and multidisciplinary activities are underdeveloped at the evaluated institutes. Urgent action is needed. A way to do that is again by stimulating research actions in collaborative, interdisciplinary research on a NTNU as well as on a RCN level. See recommendation.

Relevance for Norway

The research in the traditional domains has been very relevant for the Norwegian society. It has helped Norway to reach its present wealth, by actively supporting the exploitation of some fortunate circumstances, like the presence of abundant natural resources on its territory, and some unique geographical features. The PEC feels, however, that the tremendous possibilities created by this fortunate situation have not been used sufficiently to develop technologies that could be strategic for the country, and to participate in the development of the emerging new technologies that are shaping the world. The level of Norway's investment in research is low compared to other countries of similar levels of development (e.g. Sweden) and far below the EU target of 3%. Particularly, the poor support of basic research in engineering is of concern as ultimately it will undermine economic performance in core elements of the Norwegian economy. There is a need to consider the extent to which Norway wishes to retain a manufacturing sector, and, if this is important there is a need to invest in key areas of engineering and technology and the associated areas of basic engineering research.

Impact

Norway has a very strong institute sector that responds to the needs of the various Ministries. For engineering research and services, SINTEF dominates the Norwegian scene. With its 1700 employees and extensive building and equipment infrastructure, it has a profound influence on NTNU. As has been explained in the Panel Evaluation Reports the relation between SINTEF, with its predominantly applications-driven research, and NTNU, with a primary mission of basic research in engineering, has not always been smooth. It must be said that NTNU, through their collaboration with SINTEF, has had a sizeable impact on the Norwegian society. Ways should be found to safeguard the primary mission of NTNU, without compromising the link with SINTEF and Norwegian society.

A similar situation exists at SUC, with the presence of the Rogaland Research Institute close by. (Rogaland Research is an independent research institute in the fields of Petroleum, Aquatic Environment, Social Science and Business Development.) It seems however that there is a clearer separation of activities here compared to NTNU/SINTEF.

At NUC there is a close collaboration with the NORUT Technology branch of NORUT, located on-campus. (NORUT is a research group consisting of non-for-profit limited companies active in research in several areas relevant for Northern Norway.) Collaboration in Narvik is on cold-climate technology.

AUN has no strong cooperation with other research institutes on their campus because the many institutes present there are not active in the engineering research area.

Several research groups have close collaboration with the Norwegian Railway Administration, the Norwegian Petroleum Directorate, Norsk Hydro, the Norwegian National Security Authority, the Norwegian Building Research Institute, the Norwegian Mapping Authority, the Norwegian Centre for Project Management, the Public Roads Administration, the Norwegian Geotechnical Institute, the Norwegian Defence Estates Agency, the Norwegian Shipbuilders Association, NVE (Water resources and energy), Environmental Institute, …. The Petroleum Engineering departments at NTNU and Stavanger both have strong links with the (international) oil and service companies.

Structural Issues arising from the Panel Reports

Government-University relations: the role of the University

An important general role of the University is to provide an independent perspective for its society, which draws on the best of international knowledge and the full range of international opinion. This perspective may often include views and opinions that are at variance with fashionable views or the received wisdom of the society in which it is located. It is this function, which underpins the notion of tenure for academic faculty, which gives protection from dismissal for promulgating unpopular views.

In the area of engineering research the panel had a strong impression that the research perspective is introspective with a heavy focus on Norway and the Nordic area. As noted above leading Universities should play an important role in providing an international perspective in their subject areas through education, consultancy and policy commentary. In engineering this function was seen as relatively weak in terms of international perspective. In particular the University and faculty strategies seemed very closely bound to Government policy with little challenge to the consensus view. Efforts should be made to address this issue. A more international perspective in the University would be beneficial.

Funding of research

The present level of investment in R&D in Norway is a mere 1.67% of the GDP, contrasting with the 2.25% OECD average and well below the 3% recommended by the EU. With this figure, Norway ranks among the lowest in the industrialised world. The share of industry is slightly higher than that of the Government in the total R&D budget of 25500 MNOK in 2001. With a public R&D funding level of 0.75% of GDP, Norway belongs to the top. This means that particularly R&D funding by industry lags behind in Norway, rather than public funding.

It is interesting to see how the public spending in R&D research in Norway is distributed among the three primary receivers: universities, research institutes, and the Research Council of Norway. In 2003 they received respectively 1150, 300 and 820 NOK/inhabitant. With a population of 4.5 million, this boils down to absolute figures of roughly 5.2, 1.4 and 3.7 billion NOK.

From the data on R&D spending, it is interesting to remark that of the public funds allocated to research institutes and to the university sector (some 5 billion NOK each), in the university sector only 20% of that budget is allocated to research in technology and engineering (the other fields are: humanities, social sciences, natural sciences, medical sciences and agricultural sciences), while in the research institute sector it is 40%. This is a worrying observation, which tends to confirm the low priority of engineering research in Norway.

The situation is even worse when one looks at the distribution of the RCN budget over the divisions. About 25% of the total budget for research is allocated to the Division of Natural Science and Technology. The issue comes into very sharp focus when the engineering disciplines (without ICT) are singled out. The total direct funding received by the engineering disciplines form RCN amounts to only 18% of the budget of the Division of Natural Science and Technology. This means that of the total RCN budget less than 5% goes directly to engineering research in the university sector.

The scarcity of RCN funds and relative abundance of funding by applied research projects via SINTEF and other Institutes are undoubtedly a primary cause of the imbalance between fundamental and applied research observed by all three panels.

Public funding of the Norwegian universities is predominantly driven by education. The Departments are funded in proportion to the number of students and their achievements. There seems to be little room for funding of research. In addition, there is no well-developed research policy at university or college level. Many European universities have recognized the need to allocate a special budget for funding basic engineering research. Some establish "University Research Councils" that allocate funds on a selective international peer review basis. Special funding categories are possible. At one major European university these are: Grants for promising starters, Concerted research actions, Interdisciplinary research projects, Grants for foreign PhD students, for post docs, junior and senior fellowships. This action has had a tremendous impact on the qualitative and quantitative research output of that university. If NTNU is to make a special effort to foster the basic research component of its research groups, and make the departments more independent in their choice of the research fields, a local "Research Council" governing a special research budget might be a solution.

On the other hand, SINTEF is a major asset to the departments and research groups in terms of infrastructure, people, and budget. For NTNU it is a window onto industrial and societal reality. The same is true for the other institutes on or in the vicinity of the campus (Rogaland and NORUT). Such an intimate relationship frees the research institutes from worrying about government funding, however, at the expense of adapting their research to short-term, industrial needs.

When the Panels examined the sources of research funding it observed a wide spectrum of responses. Some groups made serious efforts to obtain EU funds and develop valuable long-term international collaborations. Others were content to accept established routes with simpler internal procedures and thus to ignore possible new funding sources. The culture of each department and group seems to be well established and to be the principal determinant of whether they are outward looking at international standards, or are more locally focused. If NTNU is to pursue successfully the strategic areas it defined in 1999, it needs to develop a funding system that rewards productivity and interdisciplinary collaboration (see above).

Actions should be taken, by RCN and by NTNU to increase the level of basic research in engineering science. In particular,

- RCN should substantially increase the funding level of research in fundamental engineering science, by creating special programmes that foster cross-disciplinary and/or cross-institutional research. Moreover, it will require very substantial support if the research groups at NUC, particularly, and SUC, are to develop to the level of those at NTNU.

- NTNU, on its part, should allocate funds for basic research in engineering science, governed by some suitable mechanism; it should consider the levy of an overhead on SINTEF money which is spent to support basic research; it should also consider providing different categories of funding: grants to promising young researchers, doctoral scholarships for foreign researchers, junior and senior fellowships to attract excellent foreign researchers, concerted actions for excellent groups, inter-disciplinary research actions.

The present system for evaluation of research proposals by RCN is inefficient, as the majority of the proposals are unsuccessful, in spite of having cost considerable preparation time. The Research Council should consider a change to a process of review of first an abstract, then a plan and finally a project.

Physical infrastructure including scientific equipment

Although the emergence of powerful virtual engineering and simulation programmes might reduce the importance of some experimental facilities in the future, physical infrastructure and laboratory equipment will continue to occupy an important place in a research institute for sometime to come, particularly in areas like hydraulics, maritime engineering, manufacturing, petroleum engineering. The PEC has noted that, in general, the facilities available for experimental engineering research, especially at NTNU and Stavanger, are very good and well-maintained thanks also to the excellent facilities made available by SINTEF, Rogaland, NOTUR (with a well-running large computer facility). This fortunate situation has led to strong experimental programmes in many groups. It was not clear, however, how the financing of the laboratories was assessed, in comparison with, for example, faculty costs. It is possible that the cost of the laboratories is not correctly perceived and that this in turn is leading to poor utilisation of space and under-pricing of applied research for clients. Any changes should be carefully considered so as to avoid damaging the existing strong programmes of laboratory-based research.

The pricing and utilisation of the laboratory spaces should be carefully reviewed from a cost perspective, to create a better cost awareness in the user. The management of some of the laboratory spaces should be improved. Care should be taken to keep the very well equipped laboratories in good order.

National cooperation including interaction with research institutes

Industry-university cooperation has been perceived by the Panels as running quite smoothly, both for the research channelled through SINTEF and for the bilateral projects. Direct industry-university cooperation can be stimulated by removing barriers (such as confidentiality), e.g. through identifying people who interface with industry while maintaining confidentiality. The establishment at the universities of an interface company, taking care of the contractual - particularly the legal - matters on behalf of the research groups can be very beneficial to alleviate the administrative burden on the researchers.

As regards whether funding mechanisms by the public sector should be different from those in industry, the PEC has the opinion that the majority of public sector funding for long-term research should be channelled through universities (e.g. for the case of research in aquaculture) so as to foster collaboration and to facilitate dissemination of research results through training of young engineers.

Finally, as already stated above, a closer collaboration between research groups within the same and in different institutions is recommended. The institutes and RCN can stimulate this by creating special research programmes that require collaboration.

International co-operation

Some research groups are quite successful in participating in European and other international research programmes. Some Nordic programmes are well established too. Other groups are active in development cooperation programmes. In general, however, the inflow of foreign researchers and visiting professors is under par. Also the opposite flow is limited: PhD students are not used to spending some of their research time abroad, except in a few departments. On the other hand, some research groups, and particularly those active in areas where Norway is strong (hydropower, dam and river engineering, waste water, marine technology, petroleum engineering), are very active in organising international conferences in Norway.

There are difficulties in working with the EU, in part because of the time and cost of travel to most EU Member States. It would be useful to identify those EU programmes where participation was strategically important and provide support for the costs of interaction and especially travel. This would also reinforce the international perspective in the selected areas. Useful ways of dealing with this issue may be found in the example of Finland, which appears to be relatively successful in winning EU contracts.

Leadership, Organization and Strategy

The departmental structure adopted in the evaluated universities is not conducive to a strong management and leadership structure, such as that observed e.g. in the Lehrstuhl-oriented institutes in Germany. An elected chairman of a Department is a scientific peer to his colleagues, and a natural leader is required to introduce some kind of leadership structure in the department. In order to ensure a more effective implementation of the formulated strategies, ways should be found to introduce a stronger leadership culture in the existing departmental structure. Means to achieve this are:

- To appoint rather than elect department/research group heads
- To offer management/leadership training not only to future leaders, but to everyone in the department, starting with the PhD students
- To provide adequate incentives for management functions
- To try to stimulate collective leadership

Experiments with professional Department heads or Deans in other countries, e.g. in the Netherlands, have proven quite positive. This is common practice in the US.

A positive impact on leadership, to provide more flexible, stimulating and creative research groups, can be achieved by industrial associate professors (professor II). Academia gains from being exposed to other cultural values and strategies found in society, e.g. research-intensive industry.

The reorganisation into fewer departments and new combinations that has been carried out recently should be critically reviewed. There are still many one-professor enterprises. Some combinations/separations seem to work counter-productively, e.g. the separation of Marine Structures from Marine Civil Engineering. This could be solved by establishing 'virtual research centres' across departments/faculties/ institutions/countries. The existing strategic plans should be used as touchstones in those considerations.

Some groups are not viable in their present form as their output is too small, sometimes because the group is too small, e.g. several groups at NUC, Solid Waste Engineering and Recycling at NTNU. For those groups, the best policy should be determined. If the research field is important or strategic the group should be stimulated or integrated into a larger entity while retaining its identity. Otherwise it is probably best that the group is closed down or absorbed by a larger unit without preservation of identity. The RAMS group at NTNU demonstrates, however, that it is not just the group size that matters in determining viability; with their 2 professors and 4 PhD students they achieve a uniform 'excellent' rating. Also, fragmentation of certain disciplines over different faculties/universities should be critically reviewed, e.g. Geomatics at NTNU and AUN.

The problem of an aging academic staff in several of the research groups is threatening to the continuity of some specialised research areas, where no young specialists are available. However, at the same time it offers unique future opportunities to re-orientate research groups by embarking on new research areas.

The RCN and the university can play an important role in stimulating closer co-operation among research groups, even across university borders, by creating funding formulas that require such collaboration (e.g. the Interuniversity Attraction Pole Programme of the Belgian Research Policy Department). See also the recommendations in section *'Increasing the efficiency of the research groups'* above.

Recruitment and mobility

Human resource management is perhaps the most important issue in every organisation. The problems of recruiting suitable people are specific for each type of organisation. The academic environment has unique issues in this respect, and there are particular difficulties in recruiting and retaining engineering faculty. Salaries for engineers in industry are generally substantially higher than in academia. Additionally, technology is no longer popular with students in contemporary society, and thus enrolment in engineering subjects is in decline and it is particularly difficult to recruit PhD students to join university research groups. (Some disciplines are of course more popular (ICT, bio-engineering) than the 'traditional' subjects (civil, manufacturing)). This last problem is further compounded by the low value placed by industry on a PhD

The Panels had invariably to listen to complaints about the difficulties of recruiting enough, suitable PhD students. Some research groups, active in projects of development cooperation, solve the problem by recruiting PhD students from the developing countries they work with, and this perfectly makes sense. However, this is a not a general solution to the problem. The issue is widespread in the industrialised world and the panel can only highlight the problem as needing attention.

Renewing interest in engineering

Ways should be sought to reverse the waning interest in engineering and engineers in present-day society ('engineers destroy the environment', 'engineers are dull', 'engineers create unemployment through automation', …). There are several ways to approach this, such as:

- showing the young people that engineering and technology 'are fun'. This has to start in secondary, even primary school by convinced, enthusiastic teachers and exemplars. Open days at the universities, technology fairs and permanent exhibitions, TV programmes, describing role models, etc. can promote engineering,
- showing that the modern technological achievements deserve respect and should not be taken for granted,
- creating the awareness that all major problems of modern society require engineers as part of their solution: energy, water, environment, health care, transportation, mobility,
- showing that the traditional engineering issues now rely on 'modern technologies' such as ICT, biotechnology, microelectronics, nanotechnology, etc. for their resolution.

Similar problems arise when it comes to hiring suitable academics at the rank of professor. The PEC believes that some measures could be taken to ameliorate difficulties of recruitment. Thus, to attract and to develop qualified personnel, the

The Principal Evaluation Committee recommends that:

- time-limited, non-tenured positions should be established between post-doctoral researcher and permanent faculty positions. The nominees should be given both research and teaching responsibilities and serve as a development level for recruitment of new faculty.
- post doc positions are assured for PhDs rated 'excellent', for research in Norway or abroad.
- if basic research is to be carried out at the regional universities the latter should develop hiring policies based on forming strong competitive research units with a clear research agenda. This cannot be achieved however without active help from RCN.
- the universities should make their important role in Norwegian society better known and publish their strategy and visions in a form that increases awareness of the importance of technical research.
- a more result-oriented salary system should be introduced to keep the most prominent researchers and attract others. Recruitment at the international level will be particularly important for NTNU.

The gender issue

It is generally very difficult to recruit women researchers in engineering. The Panels were informed that there are very few women pursuing Ph.D. degrees in Norway. Countries and institutions will find it increasingly difficult to compete internationally if only half of the available talent is utilized effectively. The leadership of the universities should take active measures to change this state of affairs.

The establishment of a working group on Gender Studies has had beneficial consequences in some European universities. Also the orientation of the study programme towards more 'feminine' interests can create rapid growth in the enrolment of women. The establishment in one European university of an Option Biomedical Engineering in the Department of Mechanical Engineering led to the enrolment of 50% of the students from the female population.

The image of engineering should be extended to awaken the interest of female students. The requirement of diverse perspectives so as to ensure that engineering solutions be viable for the whole population of users should be promoted. Role models, examples of successful female engineers in different positions (manager, researcher, professor) are known to have a large influence. Institutional barriers should be removed or lowered to attract more women. More female professors should be appointed; female students must meet female professors in their engineering courses. Finally, drawing on the gender differences in formulating research programmes and creating suitable work environments are other measures that can be taken with relatively little effort.

Innovation and Spin-off policy

In their strategic plan NTNU states that they want to stimulate entrepreneurship among students, employees and in society, and contribute to increased value creation in the nation. For this purpose, the Leiv Eriksson Nyfotek and the Gløshaugen incubator have been established and some 25 companies seem to have emerged from these initiatives. During the evaluation visits the Panels have heard very little about these initiatives. Consequently the Panel members concluded that the ideas behind the two initiatives have not yet been absorbed by the research community at the Faculty of Engineering Science at NTNU. The PEC did not study this dichotomy in detail. It might be that innovations are mainly channelled through SINTEF.

Whatever the reasons, it is the PEC's conviction that more active policies to stimulate innovation should be applied to the academic research partners, by the two mentioned institutions. There are excellent examples in Europe where inspiration can be found (e.g. Cambridge University, KULeuven R&D). Courses in entrepreneurship should be part of the engineering curriculum.

Regional policy

In Norway there seem to be 26 regional university colleges of which two are engineering colleges: Narvik University College (NUC) and Stavanger University College (SUC). Elements of these two colleges were evaluated by the three Panels.

The Panels did not get a clear picture of the role the government allocates to these colleges. One role certainly is contributing to the development of the region in which they are located. Their role with respect to research is less clear. Both colleges are allowed to award Master degrees in engineering, but are not or have just recently been entitled to award PhDs. This creates an ambiguous situation in that the colleges are entitled to develop research programmes in relevant fields, for which PhD students have to be recruited. Funding of those programmes is problematic because the funds have to be obtained on a competitive basis against established research groups, e.g. at NTNU.

The opinion of the PEC is that the role of the two colleges concerning PhD-education and research goals should be clarified. If it is a national policy to offer research and PhD education in specified areas related to regional needs then there is a need for substantial strengthening of that PhD education and research. There are several ways to achieve this:

- Developing a new institutional framework based on collaboration with established institutes.
- Allocating special funds to accelerate the swift transition of the research groups towards critical size and high quality, and by appointing high-level visiting professors for short periods to accelerate the process.

Also the question of whether or not, or when such colleges should become universities should be resolved quickly, otherwise the uncertainty will continue to absorb perhaps too much energy in ‘trying to become universities’. The outcome will of course have a profound effect on the future strategy

Recommendations

The Principal Evaluation Committee recommends that:

- strategic research plans be established at all levels, reflecting the needs of the target groups, according to a top-down/bottom-up/meet-in-the-middle iterative process. Appropriate follow-up mechanisms must be put in place to guarantee the effectiveness of those plans.

- effective leadership be stimulated in the research groups, in order to ensure a more effective implementation of the formulated strategies, by considering appointment rather election of department heads, by providing training in management to the research staff, and incentives for management functions.

- investment be made in the development of those research groups that are considered to be strategic for the future development of Norway. These might include: energy systems, oil and gas extraction technology, manufacturing, product design, product development, engineering design, operations management, materials engineering.

- prompt action be taken to increase the publication by research groups of papers in recognised archival journals.

- to prevent deterioration of the competitive position of Norway, particularly in the manufacturing sector, new research areas, now almost missing in the research agenda of the Faculties of Engineering, such as mechatronics, precision engineering, microsystems technology, nanotechnology, should be urgently considered. Activities in collaborative, interdisciplinary research should be started.

- stimuli be applied to increase the level of basic research in engineering science.
  - RCN can contribute by substantially increasing the funding level of engineering research, by creating special programmes that foster cross-disciplinary and cross-institutional research,
  - The universities can contribute by allocating part of their own funds for basic research governed by a “University Research Council”; by levying overhead on involvement of university researchers in applied research projects, e.g. via SINTEF, to support basic research; by providing different categories of funding, e.g. grants to promising young researchers, interdisciplinary research,…
  - A better organised PhD education system should be established at the universities,
  - A multi-criterion rating system for engineering research should be developed and applied within which peer-reviewed international journal publications are an important category.

- the position of education and research in engineering in Norway should be strengthened by:
  - enhancing international presence and connectivity by recruiting international faculty for both long and short term employment,
  - taking actions to counter the waning interest in engineering among the youth,
  - taking measures to enhance the recruitment process of academic staff and PhD students,
  - taking actions to address the gender imbalance in engineering academia.

- entrepreneurship among the research community be stimulated. The existing initiatives to stimulate innovation (e.g. Leiv Eriksson Nyfotek, Gløshaugen at NTNU) should be advertised more actively to the researchers.

- the ambiguities with respect to the research policy of the regional colleges be resolved by clear signals from the government and from RCN.

Appendix: Mandate for the Principal Committee

Norwegian Research in Engineering Science -
Status and Recommendations for future development

Principal Evaluation Committee

I Introduction

The objective of the evaluation
The objective of this evaluation is to assess the quality and relevance of research in engineering science in Norwegian universities and university colleges. The conclusions should lead to a set of recommendations concerning the future development of research in engineering science in Norway.

The evaluation is expected to give a basis for:
- The institutions concerned, at different levels of their organization, for further development of their research activities
- Strategic decision making by the Research Council, determining future priorities within and between individual areas of research
- Identify areas of research that need to be strengthened in order to ensure that Norway in the future will possess necessary competence in areas of importance for the nation.
- Advise to relevant ministries funding research in engineering

Organisation
Three evaluation panels have been established for major subfields within Engineering Science. The principal evaluation committee has six members, the chairman and an additional member from each of the three panels. The principal report should be based on the general findings and recommendations of the three panels.

II Mandate for the Principal Committee

The Principal committee has the responsibility to write a synthesis report based on the conclusions and recommendations in the reports of the three panels that offer an overall assessment of the state of engineering research in Norway. The report should look at engineering as a whole and include a set of recommendations concerning the future development of engineering science. An executive summary should highlight the most important findings and recommendations.

State of research and recommendations for future development
- Which fields of research in Norway have a strong scientific position internationally and which have a weak position? Is Norwegian research being carried out in fields that are regarded as relevant by the international research community? Are new developments on the international scene represented on the research agenda?
- Is there a reasonable balance between the various fields of Norwegian research in Engineering Science in view of the needs for competence in the Norwegian

society at large? Do the research groups initiate and take part in interdisciplinary/multidisciplinary activities ? Is the present research in Engineering Science relevant to the future needs of Norwegian business sector and public sector?

- What impact does the research have in society? Do research groups maintain a good network to the business sector and the public sector?

Structural Issues

The principal committee is requested to give an assessment of the overall situation with respect to some important structural issues and give its recommendations:

- *Funding of research*, the role of the institutions own funding, the Research Council and the industry. The overall situation for financial support of engineering research. Is the funding adequate and are there any recommendations regarding changes in the distribution of financial support?
- *Physical infrastructure including scientific equipment* Status w. r. t. laboratories and research infrastructure and ability to make use of the infrastructure. Co-operation related to the use of expensive equipment.
- *National cooperation incl interaction with research institutes* Contact and co-operation among research groups nationally, in particular, how do they cooperate with colleagues in the research institute sector?
- *International Cooperation*. Do the researchers play an active role in international co-operation in their individual subfields within engineering? Do researchers at different levels have sufficient experience from working in leading international research institutions?
- *Leadership, Organization and Strategy* at different levels of the institutions. Is scientific leadership being exercised in an appropriate way? Are the academic departments adequately organized? Do one find strategies with plans for research, and are such plans implemented ?
- *Recruitment* at different levels of engineering education and research, including recruitment of faculty scientific staff

Other aspects

Are there any other important aspects of Norwegian research in Engineering Science that ought to be given consideration?