Publications of the Academy of Finland 14/06

Energy Research in Finland 1999–2005

International Evaluation

Academy of Finland
Research funding and expertise

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International Evaluation

Members of Evaluation Panel

Professor Göran Andersson
Professor Alexander M. Bradshaw
Professor John Chesshire
(Chair until August 28th, 2006)
Professor Esteban Chornet
Professor Nam Dinh
Professor Adel Sarofim
Professor Josef Spitzer
(Chair from September 1st, 2006)
Professor Kari Törrönen

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Kuvailulehti

Julkaisija	Suomen Akatemia	Päivämäärä 21.11.2006
Tekijä(t)	Editor: Dr. Simo Makkonen	
Julkaisun nimi	Energy Research in Finland 1999-2005 International Evaluation	
Tiivistelmä	Suomen Akatemia kutsui kansainvälisen asiantuntijapaneelin arvioimaan Suomen energia-alan tutkimusta vuosina 1999–2005. Asiantuntijapaneelin muodostivat Prof. John Chesshire (pj 28.8.2006 saakka), Prof. Josef Spitzer (pj 1.9.2006 lähtien), Prof. Göran Andersson, Prof. Alexander M. Bradshaw, Prof. Esteban Chornet, Prof. Adel Sarofim, Prof. Nam Dinh ja Prof. Kari Törrönen. Arviointi perustui 23 tutkimusyksikön (21 yliopistotutkimusyksikköä, VTT ja VATT) toimittamiin itsearviointilomakkeisiin liitetietoineen ja vierailuhin kyseisissä yksiköissä touko-kesäkuun vaihteessa 2006. Arviointiraportin tilastollisessa osuudessa käsitellään muun muassa resursseja ja tuotoksia, kuten tutkimushenkilöstön, rahoituksen ja julkaisujen määrää. Raportissa on esitetty arviointi Suomelle tärkeimpien energia-alojen (ydinvoimatekniikka (fissio) ja turvallisuus, sähkövoimatekniikka, polttotekniikka, fuusio, polttokennot ja vetyvoima, aurinkoenergia sekä bioenergia) tutkimuksen tilasta. Lisäksi raportissa on arvioitu yliopistoyksiköiden opetuksellinen tehokkuus sekä yksittäiset tutkimusyksiköt. Energiateollisuuteen ja energiapolitiikkaan sekä energiatutkimukselle resursseja tuottavaan koulutukseen liittyen panelistit esittävät kymmenen suositusta. Yhteenvetona yleisistä suosituksista voidaan todeta: Suomen tulisi perustaa erillinen energiatutkimuksen ohjelma, jota tulisi rahoittaa merkittävästi nykyistä enemmän. Kyseisen ohjelman tavoitteet ja prioriteetit tulisi pohjautua yhtäältä kansallisen energiapolitiikan ja toisaalta teollisuuden tarpeisiin siten, että ohjelma ottaa huomioon eurooppalaisen energiateknologian kehityksen. Lisäksi ohjelmaa tulisi tukea energiatutkimuksen koordinoinnilla siten, että ohjelma tuottaa 'top-down'-ohjeistuksia tutkimusyksiköille tutkimuksen aihealueista ja antaa suuntaviivoja perustutkimukselle ja jatkokoulutukselle. Koska moneen muuhun maahan verrattuna Suomessa on asukaslukuun suhteutettuna suuri määrä energiatekniikkaa tutkivia yliopistoyksiköitä ja niillä on laaja energiatutkimuksen kohdealue, panelistit suosittelevat nykyistä enemmän yhteistyötä ja koordinaatiota sekä yliopistojen välillä että myös VTT:n ja yliopistojen kesken. Panelistit esittävät, että parhaiten tähän päästäisiin uuden kansallisen energiatutkimusohjelman muodostaman strategisen viitekehyksen puitteissa.	
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Description

Publisher	Academy of Finland	Date 21, November 2006
Author(s)	Editor: Dr. Simo Makkonen	
Title	Energy Research in Finland 1999–2005 International Evaluation	
Abstract	Commissioned by the Academy of Finland, a panel of international experts was invited to evaluate Finnish energy research carried out during the period 1999–2005. Members of the evaluation panel were Prof. John Chesshire (Chair until 28 Aug. 2006), Prof. Josef Spitzer (Chair from 1 Sept. 2006), Prof. Göran Andersson, Prof. Alexander M. Bradshaw, Prof. Esteban Chornet, Prof. Adel Sarofim, Prof. Nam Dinh and Prof. Kari Törrönen. The evaluation was based on material supplied by the 23 units (21 university departments, VTT and VATT) that were visited by the panel during the week of 29 May to 2 June 2006. The evaluation report contains statistical material on resources and outputs (research personnel, research funding and publications), and an overall appraisal of the research status in the energy fields most important to Finland (nuclear fission engineering and safety; electric power engineering; combustion technology; nuclear fusion; fuel cells and hydrogen, solar; bioenergy). Additionally, an evaluation of the educational performance of the university units and reports on the individual units is presented. Ten recommendations have been made relating to the needs of industry and policy, as well as to the educational system producing the human resources needed to carry out energy research. The overall recommendations may be summarised as follows: Finland should institute a programme of basic and applied energy research (Energy Research Programme) with substantially increased funding. Priorities and goals in this programme should be defined based on the needs of national energy policy and industry as well as take into account developments in energy technology at the European level. The programme should be supported by coordinated energy systems research. Moreover, it should provide top-down guidance for the selection of topics by the research units and give some orientation for basic research and for shaping postgraduate training. Given the high number (compared to other countries on a per capita basis) of university based research units engaged in the entire spectrum of energy research, more effort should be made to coordinate their activities. More cooperation and coordination are required, not only in the university sector itself, but also between universities and VTT. Ideally, this should occur within the framework of an overall strategy contained in the Energy Research Programme.	
Key words	Energy research, research policy, research funding, evaluation, etc.	
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Preface

The Research Council for Natural Sciences and Engineering decided at its meeting on 18th November 2005 to commission an international evaluation of energy research in Finland. The primary objective of the evaluation was to determine the scientific quality of the field of energy research in Finland during the period of 1999-2005. The evaluation covers research activities carried out in universities and research institutes representing the field.

The Research Council appointed a Steering Group to lead and support the execution of the evaluation. The Steering Group, whose term was until the end of December 2006, consisted of members from the Academy of Finland, the Funding Agency for Technology and Innovation (TEKES), the Ministry of Trade and Industry and the Finnish energy sector. The members of the Steering Group were Professor Hannu Hänninen (Chair, Member of the Research Council for Natural Sciences and Engineering, Academy of Finland), Director Jari Kostama (Association of Finnish Energy Industries), Chief Technology Adviser Jukka Leppälahti (TEKES), Technology Manager Petra Lundström (Fortum Corp.), Director Kari Saviharju (Andritz Corp.) and Industrial Counsellor Sirkka Vilkamo (Ministry of Trade and Industry). The Steering Group defined the field of energy research to include energy production and conversion. In all, 23 research units were identified as representative for the evaluation.

To undertake the evaluation the President of the Academy of Finland appointed an international Evaluation Panel with nine distinguished scientists. The members invited to serve on this evaluation panel were Professor John Chesshire (SPRU, University of Sussex, UK), Professor Göran Andersson (Power Systems Laboratory, ETH, Switzerland), Professor Alexander M. Bradshaw (Max-Planck-Institut für Plasmaphysik, Germany), Professor Esteban Chornet (University of Sherbrooke, Canada), Professor Nam Dinh (Royal Institute of Technology (KTH), Sweden), Professor Adel Sarofim (University of Utah, USA), Professor Josef Spitzer (Joanneum Research, Austria), Professor Tord Torisson (Lund University, Sweden) and Professor Kari Törrönen (EU-JRC Institute for Energy, The Netherlands) (see Appendix A for more details). Professor Torisson and Professor Törrönen were unable to participate in the site visits of the assessed units.

The Evaluation Panel was asked to characterise the energy research in Finland as a whole on the basis of individual research unit evaluations and provide recommendations on its future development. The Terms of Reference document presented in Appendix B further states that the key issues of the evaluation were strengths, weaknesses, opportunities and threats of the energy research in Finland and the individual assessed units, available resources (both research personnel and research funding), researcher training, national and international collaboration, publishing activities and the utilisation of research results.

The evaluation was based on the material provided by the units to be assessed according to the standardised questionnaire (Appendix C) and on the site visits carried out during the week of 29 May to 2 June 2006. The execution schedule of the whole evaluation is shown in Appendix D. The summary statistics of the research resources of the evaluated units is attached as Appendix E1 and the summary of the funding resources in Appendix E2. The panellists' reports on the individual energy research units are attached in Appendix F.

Panel Recommendations

In the course of the evaluation it became clear that the Evaluation of Energy Research should be seen in two directions:

- Evaluation of the results of energy research in relation to the needs of industry and policy
- Evaluation of the universities, i.e. the educational system providing the human resources needed for carrying out energy research

Hence the recommendations are grouped accordingly.

Research results-related recommendations

Recommendation 1: In view of the pressing problems of climate change, fossil fuel supply, increasing global demand and security of supply Finland should institute a programme of basic and applied energy research (Energy Research Programme) with substantially increased funding. Priorities and goals in this programme should be defined based on the needs of national energy policy as well as of industry and take into account developments in energy technology at the European level. The programme should be supported by co-ordinated energy systems research. Moreover, it should provide top-down guidance for the selection of topics by the research units and give some orientation for basic research and for shaping postgraduate training. The execution of the Energy Research Programme should make use of the flexibility and continuity provided by VTT supplemented by the university-based capacity.

Recommendation 2: Subsequent to the decision made by Finland to invest further in nuclear power, it is appropriate that strong support be provided for basic research training and education in this area at a level commensurate with the role that nuclear energy will play in the Finnish energy mix. In this respect, it is important to enhance and maintain – with support from the Finnish utilities – a nuclear-related R&D infrastructure, with emphasis on operational safety, nuclear waste and plant life management. This would enable high quality research to be done in these areas and in particular help address promptly any reactor safety issues should they arise. There is a potential danger of a demographic collapse in the nuclear research field and this should be dealt with in a timely way.

Recommendation 3: Finland's commitment to increase the use of renewable sources of energy has already led to globally recognized achievements, in particular related to bioenergy. Since there is substantial industrial capacity in this area an enhancement of R&D is recommended to both maintain and expand the technology leadership in certain areas and to achieve an economic payback through increasing export opportunities. Of particular importance are the development of transportation biofuels and questions related to securing feedstock for their production in competition with other sectors requiring biomass.

University-related recommendations

Recommendation 4: Given the high number (compared to other countries on a per capita basis) of university-based research groups engaged in the entire spectrum of energy research, more effort should be made to coordinate their activities. More cooperation and co-ordination are required, not only in the university sector itself but also between the universities and VTT. Ideally this should occur within the framework of an overall strategy (see Rec. 1).

Recommendation 5: Attention should be given to establishing a system providing a larger number of experienced, mid-career researchers. In other words, more permanent funding arrangements should be put in place for the senior research staff. Such arrangements should also include the provision of a career ladder in order to avoid the establishment of a "second class staff" compared to the teaching staff.

Recommendation 6: Mobility of researchers should be encouraged, both from within and outside Finland, by means of a larger number of competitively awarded travel and visiting fellowships. This should not just be at the professorial level. Emphasis should be on Finnish scientists travelling abroad rather than on an extensive visitors' programme, thus enhancing the existing sabbatical system of the Academy of Finland.

Recommendation 7: A swift move to encourage much earlier completion of doctoral training – say by 30-35 years of age, or even earlier – should be initiated. One action for this could be 3-4 year awards for all postgraduates - not only those participating in Graduate School. This would much shorten the PhD completion period and avoid the need for doctoral students to be financed by a succession of short research contracts (sometimes on topics not related to their own PhD work!).

Recommendation 8: Postgraduate education effectively carried out at present in VTT should be re-organised as a "Graduate School for Energy", for example in the form of Masters and PhD programmes in co-operation between the universities with a major energy programme and VTT.

Recommendation 9: Free academic research in universities remains very important. Thus the base funding component of the research budget of the units should not be reduced. Universities should not conclude arrangements with industry that restrict the publication of research results and thereby prevent the completion of PhDs.

Recommendation 10: The research of the electric power distribution and transmission groups is generally of good standard and has up to date been done mostly in collaboration with Finnish industry. The activities have consequently mostly been focussed on rather applied and fairly short-term projects. However, many of the groups have the capacity to extend their scopes to more scientific and long-term projects: The expertise in distribution systems would be an excellent basis for collaborative international projects on the integration of distributed generation. The well equipped laboratories with possibilities to simulate different weather conditions should be beneficial when establishing national and international collaborations.

1 Introduction: Energy Policy and Research Needs

Energy is one of the greatest policy challenges for the European Union and, indeed, for the world as a whole. A major step to tackle this challenge at the EU level was the "White Paper" by the European Commission 1997: Energy for the future - Renewable sources of energy, (COM (1997)599 final). This document calls for doubling the use of renewable energy sources by 2010. A second step was the "Green Paper" in 2000: Towards a European Strategy for the Security of Energy Supply (COM (2000)769 final). This document calls for a careful analysis of the role of nuclear energy including the waste and safety questions and for further technology progress in all areas of energy mix. The European Commission's most recent "Green Paper" in 2006: A European Strategy for Sustainable, Competitive and Secure Energy (COM (2006)105 final) sets out three main objectives as a framework for addressing this challenge:

- **Sustainability:** Developing competitive renewable sources of energy and other low carbon energy sources and carriers; curbing energy demand within Europe; leading global efforts to halt climate change and improve local air quality.
- **Competitiveness:** Ensuring that energy market opening brings benefits to consumers and the economy as a whole, while stimulating investment in clean energy production and energy efficiency; mitigating the impact of higher international energy prices on the EU economy and its citizens; keeping Europe at the cutting edge of energy technologies.
- **Security of supply:** An integrated approach – reducing demand, diversifying the EU's energy mix with greater use of competitive indigenous and renewable energy, and diversifying sources and routes of supply of imported energy; creating the framework which will stimulate adequate investments to meet growing energy demand; better equipping the EU to cope with emergencies; improving the conditions for European companies seeking access to global resources; making sure that all citizens and business have access to energy.

This Green Paper proposes that a number of policies, reviews, road maps and plans be introduced, in particular a **Strategic Energy Technology Plan**. Finally it recognises that "Europe must act urgently: it takes many years to bring innovation on stream in the energy sector".

Much, if not all, of this proposed European strategy requires an extensive programme of **energy research and development (R&D)**. The Advisory Group on Energy to the European Commission has developed, based on the Green Paper objectives, a report "Transition to a sustainable energy system in Europe: The R&D perspective, June 2006", which, although not necessary reflecting the views of the European Commission or any national Government, may be considered as an authoritative summary of the energy R&D needs in the EU. The report also suggests a set of priorities for the key energy sectors, summarised below.

For the **transport sector**

- Reduction in demand via common European policies, for which the Advisory Group identified specific research needs.
- Development of advanced high-efficiency internal combustion engines for use with hydrocarbons and bio/synthetic fuels as well as of improved hybrid designs. The automotive industry is active in R&D in this area.
- Development of a biomass feedstock infrastructure for bio-fuel production (the need for EU funding as well as co-ordinated public policies was recognised by the Advisory Group).

The two options of hydrogen/fuel cells and electric vehicles could be viable longer-term technologies, and should also be pursued.

With regard to **electricity generation and heat conversion technologies**, those that offer the most potential in the long run include:

- Renewable technologies including wind (land-based, off-shore and deep off-shore), solar photovoltaic, solar thermal and biomass. EU funding would, according to the Advisory Group, give added value in all these areas.
- Nuclear fission: Deployment of generation III reactors, accelerated development of generation IV reactors with different or closed fuel cycles, and concomitant waste disposal/recycling issues. Substantial EU-level R&D support along with an open public debate on issues of concern was recommended by the Group.
- Nuclear fusion: Similarly, a continuation of the European long-term commitment to international fusion R&D activities was found necessary.

Given that the use of coal will increase in Europe and globally, conversion efficiency improvements along with carbon capture and storage (so-called sequestration) were considered to be of great importance. Moreover, grid issues were also felt to be highly significant for the development of an integrated European energy system. It was expected by the Advisory Group that end use efficiency will be pursued by industry largely without support from public funds. However, in addition to public policy initiatives aimed at increasing the commitment of citizens to redue energy consumption and energy-related emissions, EU funding is warranted for innovative approaches with high potential for energy/emissions reductions across Europe, in all sectors including industry.

Further conclusions of the Advisory Group: Interdisciplinary R&D is crucially important in almost all energy fields; key areas include materials research (for operation in demanding environments), biotechnology, socio-economic and behavioural research. Energy infrastructure development is needed for bio-fuels (development of a complete/viable indigenous supply chain), nuclear fission (e.g. material test reactors), hydrogen/fuel cells (phased development of production, distribution and storage infrastructure), nuclear fusion (ITER & IFMIF), offshore wind energy (improved wind speed and power prediction) and solar thermal (test facilities). Research infrastructure development: The European Strategic Forum for Research Infrastructure should be urged to include energy technology as a high priority.

The EU energy research priorities are established in the Research Framework Programmes. The current priorities will be established in the 7th **Research Framework Programme** for the years 2007 – 2013. With regard to the topic “energy”, the following areas will be given priority:

- Hydrogen and fuel cells
- Renewable electricity generation
- Renewable fuel production
- Renewables for heating and cooling
- CO2 capture and storage technologies for zero emission power generation
- Clean coal technologies
- Smart energy networks
- Energy efficiency and savings, and
- Knowledge for policy making

The nuclear research and training activities include:

- Fusion energy research (including the construction of ITER)
- Research on nuclear fission and radiation protection

The finalization of FP7 can be expected by the end of 2006.

Parallel to FP7 a second initiative was started by a number of industrial sectors with the support of the European Commission (EC): The European Technology Platforms (ETP). These initiatives aim at identifying and coordinating the future technology development needs in the sectors by defining a Strategic Research Agenda (SRA) to be submitted to the EC for consideration in the future calls of FP7. Among the ETPs under development are a few on energy related topics: Hydrogen and Fuels Cells, Biofuels, Forest Based Sector (Bioenergy), Zero Emission Fossil Fuel Power Plants, Electricity Networks of the Future, Photovoltaics, Solar Thermal Technology and Sustainable Nuclear Fission Technology. Industrial and research groups in Finland are actively contributing to these ETPs and their SRAs.

For Finland, the energy issue is even more important than for the other EU member states. The energy consumption per capita in Finland is the second highest after Luxemburg. If the EU-25 average is 100, the consumption in Finland is 188.3 (2003), very close to that of the US, which on this scale is 207.3. The consumption per capita in Japan is only 107.2 (source: EU integration seen through statistics, Eurostat 2006). The same statistics indicate that the energy intensity as measured by energy consumption per unit GDP, has improved in EU-25 by 7% between 1998 and 2003, but in Finland by only 3 %.

Finnish energy consumption is characterised, however, by greater diversity of the energy mix. The latest EU-25 figures are from 2003 (EU integration seen through statistics, Eurostat 2006); figures for Finland are available until 2005 (Nuclear Energy in Finland, national survey paper 2006, VTT and Energy in Finland 2005, Statistics Finland, 2006) and a comparison is shown in Table 1 Gross consumption of energy by fuel (%) in EU-25 and Finland below.

The Finnish Government has recently formulated a national strategy to fulfil the Kyoto protocol (Lähiajan energia- ja ilmastopolitiikan linjauksia – kansallinen strategia Kioton pöytäkirjan toimeenpanemiseksi. Valtioneuvoston selonteko eduskunnalle 24. päivänä marraskuuta 2005), but only one page of the report is devoted to energy technology development. However, the main statement is that technology development and its funding are still the main way to achieve energy and climate policy targets. It also recommends that public funding for industry-led projects should remain at least at the same level as during the past years; this is partly in contradiction to the statements of the importance of technology development.

Table 1. Gross consumption of energy by fuel (%) in EU-25 and Finland

	EU-25 2003	Finland 2003	Finland 2005
Oil	37	25	27
Coal	18	17	10
Natural gas	24	11	11
Nuclear power	15	16	18
Renewables	6	31 (1)	34 (1)
Note (1): Renewables include in Finland the following (not all – strictly speaking – renewable):			
Hydro and wind		2	3
Peat		7	5
Wood-based fuels		19	20
Others		2	2
Net import		1	4

The main areas for development are indicated and include renewables and energy efficiency. More specifically, cogeneration, energy production by industry, decentralized and efficient energy production are mentioned. Development and utilisation of bio-energy and bio-fuels are specifically highlighted.

In addition to the direct impact on new energy technologies (supply and efficiency related) and thus on reaching energy policy goals, energy R&D supports the economic development of the country as a whole. Successful developments are offering business opportunities for industry both in the domestic and the international market place. In Finland this is particularly relevant for the bioenergy industry and the electric utility industry: Biomass conversion equipment already has an internationally recognised high standard and the performance of nuclear power plants in Finland has been outstanding. Thus energy R&D in these areas can build on excellent know-how providing the basis for a further successful development of both the energy system and the energy industry.

2 Statistics on Finnish Energy Research

2.1 Research units and research areas

The evaluation of Finnish Energy Research in 1999–2005 covered 23 research units (listed in Table 2). The units evaluated by the Panel were either a university department or an independent research institute or a relevant part of it. Table 2 shows the total full-time equivalents (FTE) in energy research in these units in 2005.

The laboratory of Advanced Energy Systems at TKK was divided into two separate units, because their research topics, solar energy (unit 9) and nuclear (unit 23), differ substantially from each other. VTT (unit 20) is active in several energy research fields and stands out in its size and funding structure compared to the other units. Therefore, in certain statistics, the results have been presented both including all 23 units and excluding VTT.

Table 2. Assessed units and their host organisations

Key	Name of unit	University/Research institute	Research personnel 2005 (FTE)
1	Renewable Energy Programme	University of Jyväskylä (UJ)	110
2	Department of Energy and Environmental Technology	Lappeenranta University of Technology (LUT)	84
3	Laboratory of Electric Power Systems	Lappeenranta University of Technology (LUT)	71
4	Department of Process and Environmental Engineering	University of Oulu (UO)	20
5	The Laboratory of Energy Economics and Power Plant Engineering	Helsinki University of Technology (TKK)	10
6	Laboratory of Energy Engineering and Environmental Protection	Helsinki University of Technology (TKK)	19
7	Laboratory of Applied Thermodynamics	Helsinki University of Technology (TKK)	16
8	Internal Combustion Engine Laboratory	Helsinki University of Technology (TKK)	13
9	Advanced Energy Systems: (New Energy Technologies)	Helsinki University of Technology (TKK)	16
10	High Voltage and Power Systems Engineering	Helsinki University of Technology (TKK)	19
11	Laboratory of Electromechanics	Helsinki University of Technology (TKK)	22
12	Institute of Energy and Process Engineering	Tampere University of Technology (TUT)	49
13	Institute of Materials Chemistry	Tampere University of Technology (TUT)	17
14	Institute of Automation and Control	Tampere University of Technology (TUT)	2
15	Institute of Electromagnetics	Tampere University of Technology (TUT)	21
16	Institute of Power Engineering	Tampere University of Technology (TUT)	23
17	Department of Electrical Engineering and Automation	University of Vaasa (UV)	11
18	Heat Engineering Laboratory	Åbo Akademi University (ÅA)	12
19	Process Chemistry Centre	Åbo Akademi University (ÅA)	47
20	Energy and Pulp & Paper	Technical Research Centre of Finland (VTT)	560
21	Projects related to energy research	Turku School of Economics and Business Administration (TuKKK)	8
22	Research area III: Environment and infrastructures	Government Institute for Economic Research (VATT)	12
23	Advanced Energy Systems: Nuclear	Helsinki University of Technology (TKK)	17
Total		23 units	1,179

The Panel based this evaluation on its consideration of the written self-assessment forms provided by the units, information supplied by the Academy and the site visits to and discussions with each of the units. The Panel also received copies of published papers the units considered their best. At several site visits, additional information was requested from the units because of missing data or misinterpretations in the original self-assessment forms. Yet, several units had not provided all requested information, for example the SWOT analysis. Thus assumptions had to be made by the panel members.

To facilitate the 25 site visits (3 to VTT) in one week the Panel was divided into two smaller teams. The time available for most site visits was not sufficient to visit the laboratories and to discuss informally with the teams as fully as wished. The Panel realises that this might have caused disappointment from the units' side.

The evaluated units represent a wide range of research activities in the energy sector and many units have several key research areas, even though some of the units have concentrated on one or two key areas as presented in Table 3a. The division of research by various energy topics is presented in Table 3b.

Table 3a. Key research areas in the energy sector as given by the assessed units (75–100% of used research time = 'oooo', 50–69% of used research time = 'ooo', 25–49% of used research time = 'oo' and 1–24 % of used research time = 'o')

Unit	Energy production	Power plants	Emission control	Energy infra-structure	Energy conversion	Industrial energy efficiency	Future energy sources (solar, fuel cells, fusion etc.)
1		o	o	o	o	o	o
2	o	o	o	o	o	o	o
3	o			oo	oo	o	o
4		oo	oo	o		o	
5	o	o		o		ooo	
6			oo		oo	oo	
7	oo	o			ooo	oo	ooo
8					oooo		
9							oooo
10				oooo			
11	o	o	o		oo	o	
12	o	o	oo	o	oo	oooo	o
13							oooo
14	oo	oo	o			oo	
15	o		o	oo		o	o
16				oooo			o
17		o		oo	o	o	oo
18		o	o		o	oo	o
19		oo	oo		o	o	o
20	oo	o	o	o	o	o	o
21	o	o	o	oo	o	o	o
22			ooo			o	o
23							oooo

Table 3b. Key activity areas in different energy topics (75–100% of used research time = 'oooo', 50–69% of used research time = 'ooo', 25–49% of used research time = 'oo' and 1–24% of used research time = 'o')

Unit	Fission energy	Fusion energy	Combustion	Bio-energy	Hydro power	Wind energy	Solar energy	Peat energy	Ind. energy efficiency	Fuel cells	Electrical	Other
1	o	o	o	o		o	o	o	o	o		
2	o		o	oo	o	o		o	o			
3				o	o	o	o		o	o	oo	
4			oo	o				oo	o			
5			o	oo					oo		o	
6			oo	oo					oo			
7			o	o		o			oo	oo		o
8			oooo									
9										oooo	o	
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13							oooo					
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15		o				o			o			ooo
16											oooo	
17						oo			o		ooo	
18			oo						oo			
19			oo	oo				o	o	o		
20	oo	o	o	o	o	o	o	o	o	o	o	oo
21				o	o				o			ooo
22												
23	o	oooo										

2.2 Research personnel

In 2005, the total number of FTEs related to energy research was 1,179 in the assessed units. During the seven-year period FTEs have increased by more than 50% (Appendix E1).

In 2005, the research personnel FTEs were 879 (Appendix E1), of which 503 were located at the universities. VTT alone stood for some 42% of the research FTEs. The development of the research personnel in 1999–2005 is shown in Figure 1.

The FTEs of research personnel represented on average 70% of the total staff. At the university units the number of technical or other assisting personnel is much lower compared to VTT, since part of the administrative effort at the university units is carried out by the central university administration.

Figure 1. The development of research personnel as FTEs in 1999–2005

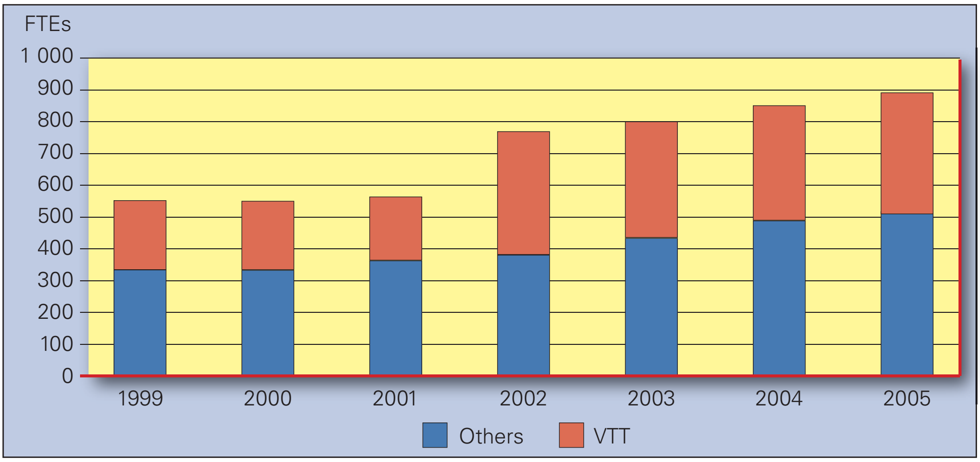


Figure 1 describes quantitatively the leading position of VTT in Finnish energy research. The organisational change in VTT in 2001–2002, when VTT Energy and VTT Chemical Technology merged into VTT Energy and Pulp & Paper, resulted in a major nominal increase in national energy research resources. However, this was not a real increase, since teams doing energy-related research (and not included in energy research before) were just transferred to a new component of VTT. In general, noticeable proportional increases in energy research personnel occurred in Renewable Energy (UJ), Institute of Power Engineering (TUT) and Projects Related to Energy Research (TUKKK) (Appendix E1).

The size of the assessed units is presented in Table 4. A majority of the units (15 out of 23) had less than 20 energy researchers on average, when using FTE per annum as a parameter. The average size was 31 researcher FTEs per unit. If VTT is omitted, the average unit size was 18 researcher FTEs. However, the median size was only 13.

Table 4. Distribution of number of researchers (see Appendix E1)

Number of researchers (FTEs)	Number of units
–10	5
10–20	10
20–30	2
30–40	3
40–50	2
50–	1
Total (n=707)	23

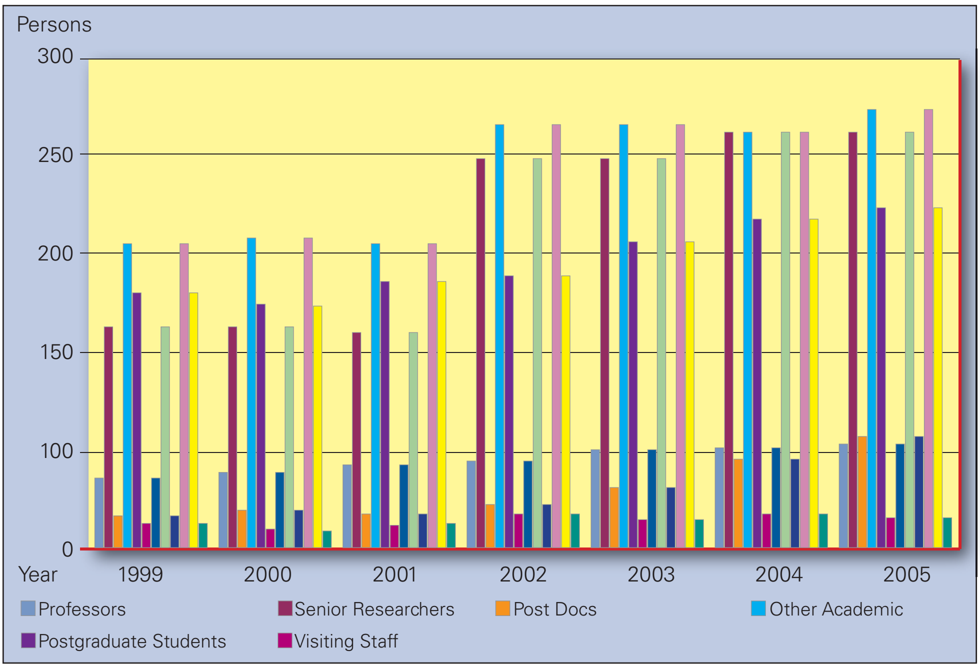
Table 5 shows the distribution of the number of professors in the evaluated units during the period of 1999–2005. Most of the units (n=18) had three or less professors. The two units with the largest number of professors in 2005 have increased the number of professors from four to 14 and from seven to 12 during the evaluation period, as using FTE years as a parameter.

Table 5. Distribution of number of professors in units on average during 1999–2005

Number of professors in a unit	Number of units on average	Number of units in 2005
0–1	11	12
1–3	7	6
3–5	2	1
5–7	1	2
7–9	2	0
9–	0	2
Total (n=54 on average, n=63 in 2005)	23	23

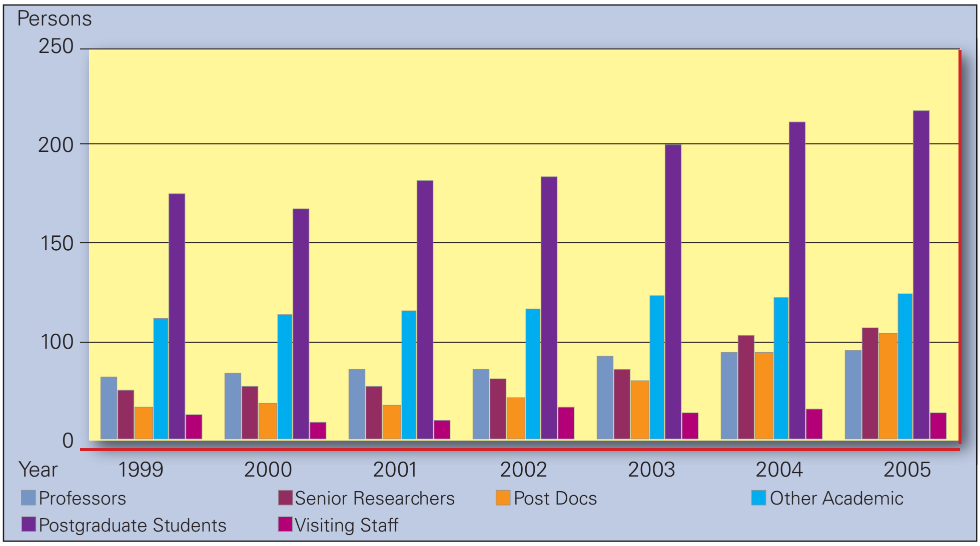
To study the units' research personnel structure in more detail, the researchers were divided into five categories: professors, senior researchers, postdoctoral researchers, other academic staff, and postgraduate students. The variation in personnel in these different categories during the evaluation period is shown in Figure 2. The professor FTEs increased by 48% (from 43 to 63) compared to senior researchers' 88% (from 134 to 254). For postdoctoral researchers there is a significant increase of 258% (from 18 to 68). For other academic staff and postgraduate students the increase is 44% and 33%, respectively. The number of visiting researchers has remained at the level of 16 FTE years during the evaluation period.

Figure 2. Research personnel structure of the units, including VTT



Note that the conclusion from Table 5 and Figure 2 may be distorted since the positions professors and postgraduate students do not apply to the structure of VTT. Excluding VTT, the figure looks significantly different (see Fig. 3). At the universities, the proportion of senior scientists of research personnel is much lower than at VTT. Still, at the universities there was one professor/senior scientist FTE per two postgraduate students in 2005.

Figure 3. Research personnel structure of the university units



2.3 Funding

The major public research and development funding actors in Finland in 2005 were Tekes (448.4 M€), universities (416.7 M€), Government research institutes (259.4 M€), Academy of Finland (223.5 M€), and other organisations (246.0 M€) with a total of 1,594 M€. The income for energy-related research from public sources (excluding core funding) by the assessed units in 2005 was 20,7 M€ representing 1.3 % of total public Finnish research and development expenditure. Total energy research-related income (including the funds needed for education) of the evaluated units in 2005 was 80 M€ and during the 7-year period 448 M€ (Fig. 4). (See also Appendix E2).

On average, the core funds of the evaluated units amounted to 36.8% of total funding in 2005. However, the amount of core funding (which includes the funds needed for education) has almost doubled during the evaluation period. At the same time, the total annual external funding increased from 29.8 M€ to 50.6 M€. The development of the distribution of total funding of the assessed units is presented in Figure 4.

The evaluated units received funding from several sources. Government budgetary funding was the largest with 30% (Fig. 5). Almost an equally large share came from industry (28%). Tekes' contribution was 19% while the Academy of Finland stood for 3% of energy research funding of the evaluated units. The EU and other foreign funding sources represented 8% of the research income. The total core funding including budgetary and other core funding was about 35 %. (See Appendix E2 Table 2)

Figure 4. Distribution of total funding of the assessed units

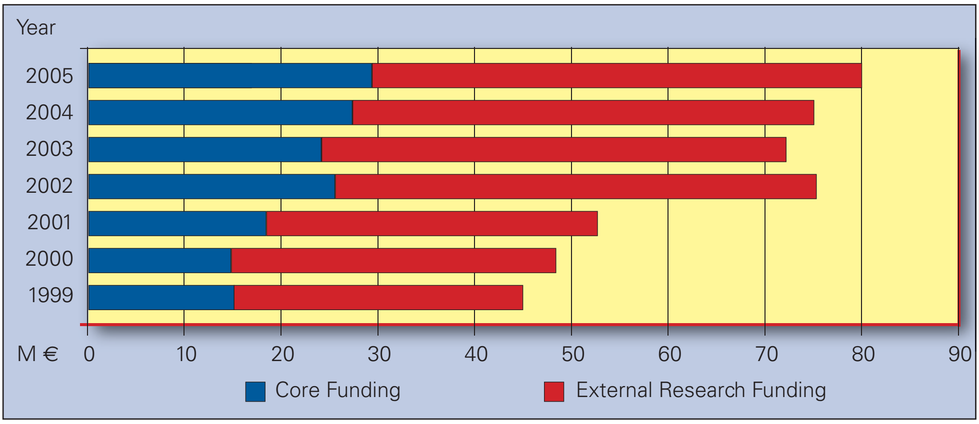
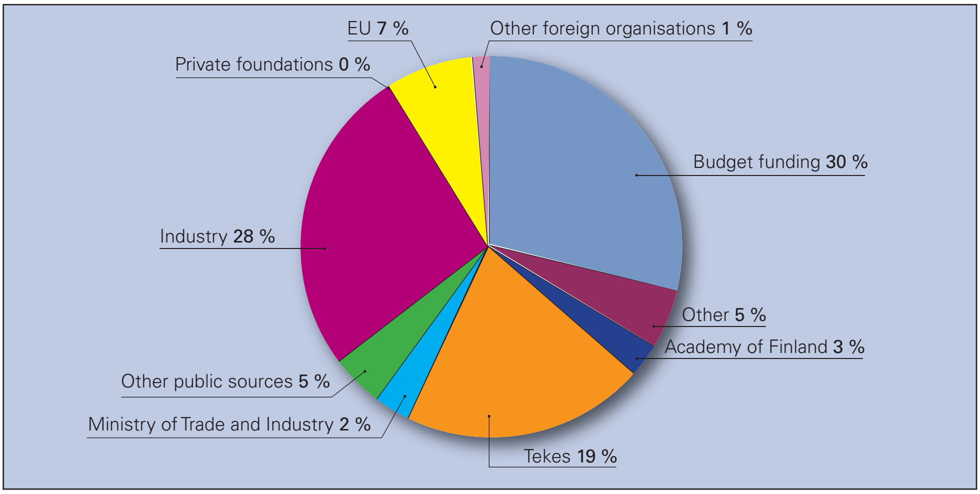


Figure 5. Total funds for the assessed units from 1999 to 2005



External funding from industry has almost doubled from 10.9 M€ in 1999 to 21.7 M€ in 2005 (Fig. 6a). At the same time, Tekes share has increased from 10.7 M€ to 13.9 M€. Funding from the EU has increased from 2.8 M€ in 1999 to 6.9 M€ in 2005. Figure 6b shows the situation without VTT. For universities, Tekes was the main funding source (36%) followed by industry (26%). The Academy of Finland has been the third largest financer with 12.0 M€ in 1999–2005 corresponding to 13% of the universities' research income.

Figure 6a. Development of external funding of the assessed units from different sources, including VTT

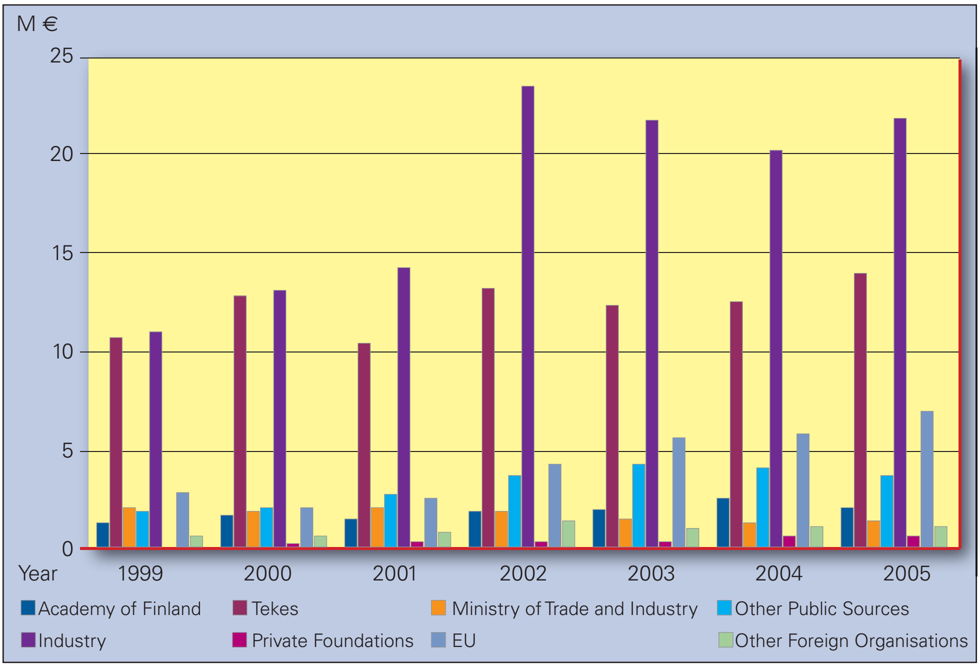
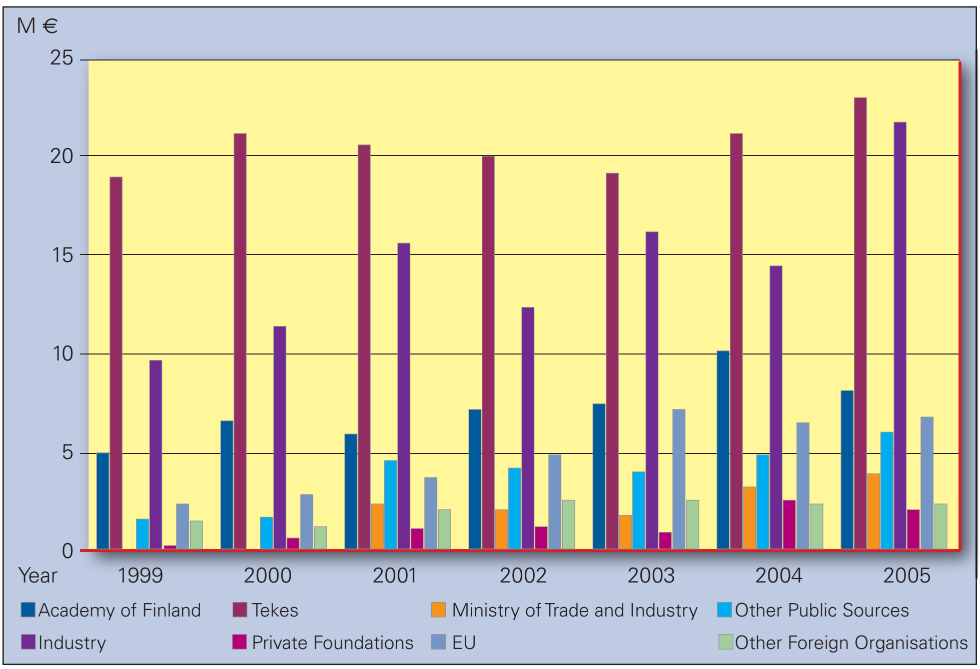


Figure 6b. Development of external funding of the university units from different sources



2.4 Researcher training

Note that this chapter does not apply directly to VTT or VATT since their mission does not include formal researcher training. Indirectly, VTT contributes to researcher training through its cooperation with universities by integrating (employing) graduate students in its research projects.

During the 7-year evaluation period a total of 169 doctoral theses related to the energy field were completed in the evaluated university units. Only 16.5% of these doctors were female. In 2005, the evaluated university units produced altogether 29 doctoral degrees. This represented about 2% of total annual doctoral production in Finland in 2005. VTT also reported 28 doctors to have completed their theses during the evaluation period. Most of these doctorates have been awarded in a university unit involved in the evaluation.

According to the information provided by the evaluated university units, the largest number of doctoral degrees was awarded by the Laboratory of Electric Power Systems (LUT) with 22 completed doctors and the Process Chemistry Centre (ÅA) with 18. Ten units out of 21 awarded less than five doctors during the 7-year period, yielding less than one doctoral degree annually per unit (Table 6).

Table 6. Distribution of completed doctoral theses in 1999–2005 in the evaluated university units

Completed theses	Units
0	2
1–5	8
6–10	5
11–15	2
16–20	3
21–	1
Total (n=169)	**21**

The number of completed doctoral theses per university professor is presented in Table 7. Five units have been able to produce more than nine doctoral degrees per professor, while ten units have produced less than three doctoral degrees per professor during the 7-year period.

Table 7. Distribution of number of completed doctoral theses per professor by unit during the evaluation period

Number of doctors per professor	Number of units
0–1	4
1–3	6
3–5	3
5–7	1
7–9	2
9–	5
Total (n=169)	**21**

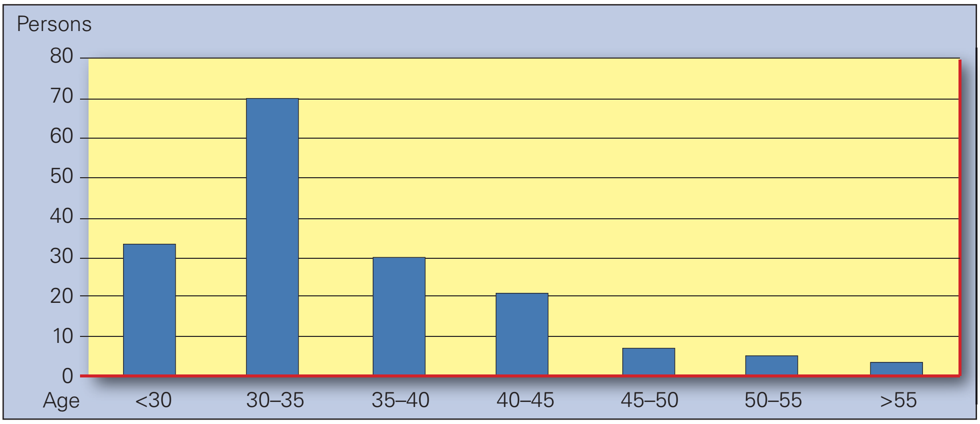
The age for completing the doctoral degree is presented in Figure 7. 61% of doctoral students completed their degree before the age of 35, whereas some 21 % of the doctoral theses were completed at the age over 40. As a reference, the average age for completing the doctoral degree in Finland was 36.3 years in 2003 and 30% of doctoral students completed their theses before the age of 30. In 2004, the average age for completing the doctoral degree in Finland was 36.3, and in technical sciences it was 31.8 years. (Statistics Finland)

The units were also asked to provide statistics for the current employers of PhD's who completed their theses during the evaluation period. As presented in the Table 8, 39 % (n=66) of them continued their research at the same university from which they graduated and 30 % (n=55) were employed by national industries. The third largest employer has been the Finnish public sector and only 4 % were continuing their research career at an international university.

Table 8. Current employers of PhDs who completed their doctoral thesis in 1999–2005

	Same University	Other Finnish University	International University	VTT	Public Sector	National Industry	International Industry	Unknown	All
1	2		1			2			5
2	8		2	1	3	1		2	17
3	12					10			22
4									0
5	1			1	1	1			4
6	2			1		1	1		5
7	1			1		2			4
8	1							1	2
9	2			2	2	3	1		10
10	2		1	1		2			6
11	3		2		1	8	1		15
12	5				2	4	1		12
13	2		1		1	3		1	8
14	2					1			3
15	3				1	2	1	1	8
16	4			1					5
17	1	1							2
18	3	1			1	2			7
19	8	1	0	0	3	4	1	1	18
20				(26)	(1)	(1)			(28)
21	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	4			4	4	4			16
	66	3	7	12	19	50	6	6	169

Figure 7. Age for completing doctoral degree (n=169)



2.5 Publication activity

The units have reported the number of scientific publications during the period 1999–2005 using four categories: articles in refereed international journals, articles in refereed international edited volumes and conference proceedings, articles in refereed Finnish scientific journals, and articles in refereed Finnish edited volumes and conference proceedings (as presented in Table 9).

A total of 3,804 scientific articles were published out of which almost 92% in international publications and 42% in refereed international journals. Of the 1,602 internationally refereed publications, 54% were submitted by 3 units (Advanced Energy Systems: Nuclear at TKK, Process Chemistry Centre at ÅA and VTT). The real number of publications is likely to be smaller than shown in Table 9 because of joint articles of the assessed units.

Table 9. Publications of the assessed units in 1999–2005

International		National		Total
Journals	Edited volumes and conference proceedings	Journals	Edited volumes and conference proceedings	
1,602	1,889	35	278	3,804

Figure 8 compares the publication activity of the evaluated units. The annual production rate per researcher exceeded one internationally refereed journal article in only three units. The average publication rate is 0.5 articles per year.

The distribution of refereed international articles per professor per annum by unit is described in Table 10. The average number of international journal publications per professor per year was 3.3 articles, when TUKKK and VATT were excluded due to the fact that these units did not have any active professors.

Figure 8. Articles in international journals per researcher FTE per annum by unit

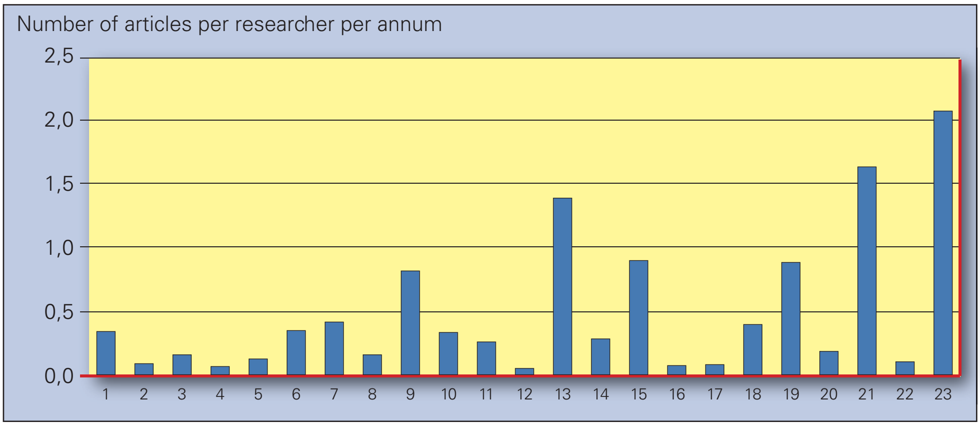


Table 10. Distribution of refereed international articles per professor per annum by unit

Articles in refereed international journals per professor per annum	Number of units
0–1	5
1–3	4
3–5	5
5–10	1
10–20	5
20–	1
Total 1,100 articles, 7 years, 54 Professors	21

The units were also asked to report their output in other relevant activities, such as number of patents, computer programs and algorithms, visiting lectures, visits in radio and television programmes and journals popularising science and other output. The units reported 59 computer programs and algorithms, 711 visiting lectures, and 1,135 radio, TV or journal interviews. The total number of patents was 174 out of which 74 were awarded to VTT, 44 to the Laboratory of Power Systems of LUT and 22 to the Process Chemistry Centre of ÅA. Eight units reported no patents. Table 11 describes the distribution of the number of patents during 1999–2005.

Table 11. Distribution of patents in units

Number of patents	Number of units
0	8
1–2	7
3–5	4
6–10	1
11–50	2
50–	1
Total (n=174)	23

2.6 National and international cooperation

The units have active national cooperation with each other, with other research units not participating in this evaluation, and especially with national industry. In addition, especially the units of LUT, UJ, TUT and UV have very active cooperation with local SMEs, local polytechnics, and new kinds of organisations, such as SENTRE (a network of business, research and education developing sustainable solutions for sustainable energy).

During the 7-year period the researchers of the units have spent a total of 1,237 FTE months as visitors abroad (periods exceeding a minimum of 1 month). This amounts to 2% of the research personnel FTE years. Visiting researchers and visiting research students spent 996 FTE months in the units during the 7-year period, which amounts to 1.6% of the units' total active research time.

Five units had no visits abroad and six units had no foreign researchers visiting their unit during the evaluation period (Table 12). Two units had neither visits abroad nor foreign visitors. On the other hand, one unit, Advanced Energy Systems: Nuclear (TKK), had more than 200 FTE months in visits abroad and also more than 100 FTE months of foreign visitors. VTT's staff spent 437 FTE months on visits abroad and the cumulative time spent by energy research visitors at VTT amounted to 413 FTE months during the period 2001–2005 (no data available from 1999 and 2000).

Table 12. Distribution of visits (minimum of 1 month per visit) by FTE months per unit

FTE months	Visits abroad	Visits to units
0	5	6
1–10	4	2
11–30	4	7
31–50	5	4
51–100	3	2
101–200	0	1
200–	1	0
Total (1,237 & 996)	23	23

The questionnaires did not include any specific parameters to quantitatively measure national and international collaboration. In particular no information was available to evaluate the involvement in international research projects, for example within the EU Framework Programmes. Hence, the evaluation, key findings and conclusions regarding the amount and the quality of national and international collaboration is solely based on the Panel members' qualitative analysis of the descriptions given in the self-evaluation forms, short unit visit presentations and the panellists' own judgements.

3 Key Findings and Conclusions

3.1 Scientific quality of energy research

3.1.1 General aspects

There are 20 universities and 31 polytechnics in Finland. Universities that did not undertake significant volumes of energy-related research were not evaluated by the Panel. In addition, much energy-related research, some 60 % of the national total, is undertaken by VTT Technical Research Centre of Finland. Finland had a population of 5.3 million people at the end of 2005, meaning on average a relatively low population 'catchment' of 265,000 people per university. Finland is noted for its high R&D/GDP intensity (3.5%) within the EU and OECD. But, even so, the relatively large number of higher education institutes participating in energy research means that resources – and especially research resources – are spread comparatively thinly between universities and units. This comment does not apply to VTT.

It was clear to the Panel that some universities (and many of their research units) have a long and excellent scientific research tradition and reputation, seeking to compete at least on EU-wide quality terms, and occasionally on global terms. Other universities and units place greater emphasis upon education and postgraduate training. In some cases this was primarily to meet the needs of their local industrial and civil society base. Likewise some university units place very heavy emphasis on high-quality basic research, using international refereed journals as their primary route for publications. Others see their role as undertaking much more applied, but still high-quality, research with the output taking a much wider range of forms – journals, conference proceedings, technical manuals and patents.

Marked differences in the pattern of research output, and of its dissemination, are found across different engineering, science and social science disciplines. In plasma physics, a hallmark of distinction is perhaps highly-cited articles in internationally refereed mainstream journals. In other fields, chairing a high-profile government advisory board, or advising Parliamentary committees are activities seen to accord great merit. Thus 'excellence' must be regarded as nuanced. With these, and similar, provisos in mind, the Panel provides in later sections its insights and judgements on the scientific quality of the research and doctoral training it evaluated.

3.1.2 Quality in specific fields

Nuclear fission engineering and safety

In the sub-field of fission energy, research and researcher training was concentrated to three units among the 23 units reviewed by the Panel, namely to the fission-related units at VTT, TKK and LUT. It is noted, however, that although these units are key players in fission energy, the present review does not cover all important players in Finland's fission energy research, which, due to the field's multidisciplinary nature and breadth, are scattered in other organisations and units.

The activity in fission technology and fission safety in Finland is well coordinated nationally within the SAFIR programme for reactor safety research, which also brings on board other players (e.g. STUK – the Radiation and Nuclear Safety Authority of Finland and Fortum Corp.). Thanks to a visible national policy in nuclear energy and outstanding performance of national nuclear industry, Finnish research on nuclear power plants' operational performance and safety has achieved broad national and international visibility. VTT is well represented in EURATOM projects. Whilst the research programme may have served several good purposes and achieved the respective goals (e.g. developing and maintaining expertise, collaboration and training in fission technology), scientific quality and scientific impact of the basic research in fission energy are considered rather low. The effort is fragmented in many topics, being thin and probably sub-critical, resulting in lack of identifiable achievement and leadership at international scale. A low output of publications in peer-reviewed scientific journals is worrisome. In this respect, there is no topical area in fission reactor technology and safety undertaken by the units visited by the Panel that could be defined as having international recognition and cutting-edge advantages.

In general, the number of doctoral degrees awarded in Finland (VTT/TKK/LUT) over the review period 1999–2005 in reactor technology and reactor safety is low. The average age of a PhD candidate on completion of a thesis in this field is high. The Panel was given an impression that PhD training is largely built on a mix of research projects and contracts. This approach may be efficient but may also have a negative effect on the focus, coherence and even the continuity of PhD research. The age profile of existing nuclear engineering and safety personnel in Finland, as elsewhere in the EU and the OECD, is becoming old; and many such employees are nearing retirement. A conscious effort is now needed to attract talented, young, postgraduate students in these fields, and to provide them with more appropriate and focused conditions in which to undertake doctor-specific research.

The Panel feels that Finland's nuclear sector would benefit from a more aggressive and strategically-minded effort in the training of scientists and engineers in the fission field. It appears timely to establish an MSc programme in nuclear engineering (including both the fission and fusion components). This would both benefit Finland and attract international talents. Finland is now in a leading role in the OECD and globally, as the first country in the world to build and operate an EPR-type Generation III nuclear power plant. The Panel also recommends stronger coordination in nuclear engineering education with other Baltic Sea countries.

Electric Power Engineering

Research in electric power is essential in order to provide expertise and knowledge to the maintenance and development of one of the most important infrastructures in a modern society. Each country has its own specific needs and requirements, and our general conclusion is that the electric power research activities in general satisfy very well the requirements of Finnish society and industry. The pure scientific and academic level of the research could be improved, which is elaborated below.

In the electric power field research is mainly carried out at TKK, LUT, TUT and UV. The research covers the areas of electric power distribution, transmission, electrical machines and power electronics. Among the units evaluated there is a strong focus on the first two areas, but significant activities in the latter two also exist. Many of the units involved are also participating in the Finnish Graduate School of Electrical Engineering, which seems to play a role as coordinator of the activities within academia on this topic. The school and the way it is operated and interacting with the member universities could be considered a model for other areas. The electric power units at LUT and TUT are the largest ones and, for the time being, the leading ones in Finland, both concerning volume and technical and scientific quality. They have both excellent cooperation with industry and very good laboratory facilities. The UV unit has started its activities quite recently, but thanks to dedicated work by unit members, strong industrial support and excellent laboratories it has already achieved quite impressive results. If the current development trend is maintained the UV unit would probably, within a couple of years, be in their field at the same level as the LUT and TUT units. At TKK, activities are also in a build-up phase and aiming at covering areas that during the last few years have not been researched to any larger extent by other units in Finland. One such area concerns transmission systems, which has not been very actively researched in Finland. This initiative by the TKK unit is essential for the electric power industry and research in Finland, and it should be encouraged.

The four units mentioned above have all excellent industrial contacts and cooperation, mostly with Finnish companies or with local branches of international companies. They have been very successful in attracting funding from these companies for rather applied and short-term projects, which unfortunately has resulted in that, in general, the more scientific and academic research has not always been actively promoted. A sign of this is the overall relatively small number of publications in peer-reviewed journals. It should, though, be mentioned that a few research fields differ significantly from this general statement. Furthermore, the number of international cooperative projects is surprisingly small in relation to the volume and quality of the activities of the different research units. The units should, at least in a number of areas, be attractive partners in international projects, EU-financed and others. It is recommended that the scientific and international profiles of the units be strengthened.

Besides these four units, electric power research is carried out at the Institute of Automations and Control and at the Institute of Electromagnetics, both based at TUT. The focus of the research at these institutes is on other topics, and energy research within these institutes seems to be marginal. This is believed to be a sub-optimal solution and it is recommended that these activities be either re-located or that stronger collaborations be sought with other units active in energy research. This would be beneficial for these small units.

Combustion technology

Combustion pervades our everyday residential and commercial heating, thermal processing in industry, steam generation for electricity production, and the motive power in spark-ignition engines, diesels and gas turbines. It is therefore appropriate that 13 of the 23 units evaluated listed activities in combustion, with combustion contributing a major percentage (>25%) of the activities at units 4 (UO), 6 (TKK), 8 (TKK), 12 (TUT), 18 (ÅA), and 19 (ÅA) and 20 (VTT Otaniemi). The strengths of the activities reported are in biomass utilisation, fluidised bed combustion, combustion modelling and combustion diagnostics. An increasing emphasis of the combustion activities is on biomass utilisation. This is fitting, given Finland's large forest resources. Fluidised bed combustion is particularly suited to the handling of biomass fuels with variable reactivity, ash content, and ash fusion temperatures. Theoretical research at the different units has been conducted at a molecular level, on the modelling of the fluid dynamics of single- and multi-phase systems, and on systems dynamics and control of entire plants. Complementary experimental studies have been conducted on scales ranging from the single-particle to the developmental stage in both atmospheric and pressurised fluidised bed reactors. The experimental facilities have been supported by novel diagnostic capabilities ranging from endoscopic probes to look into heavily particulate-laden environments to exquisitely detailed characterisation of particle size and composition distributions. Researchers in Finland are among the world leaders in the area of fluidised bed combustion, based on the publications in high impact journals, invitations to present invited plenary lectures at international symposia, and service on advisory boards. They have led the development in in-bed capture of sulphur oxides, the control of nitrogen oxides, the characterisation of particulate emission and the management of ash. The strong research contributions to fluidised bed combustion and gasification historically supported the lead positions that were taken by Finnish manufacturers on the international boiler markets. Researchers in Finland have also taken a lead position in the study of combustion in black liquor boilers and are well positioned to develop new technologies on biomass gasification and biorefineries (see section on bioenergy below). The research in these areas not only addresses local needs but also has export potential. Biomass-derived fuels are not constrained to stationary combustion, and the activities on both the catalytic synthesis of biodiesels and the impact of biodiesel on combustion represent important efforts that have the potential to decrease the dependence on imported oil in transportation fuels as well as to develop technologies with export potential. The emphasis on renewables fuels is particularly important in view of increasing global pressures to reduce the emission of greenhouse gases and to change over to sustainable energy sources.

While there is some work on carbon capture and sequestration (CCS), it is considered a small effort and a technology that has limited advocates. Since Finland has adopted an aggressive programme to reduce CO_2 emissions by energy efficiency, nuclear and biomass utilisation, the low investment in CCS can therefore be justified given that it is not applicable to automotive emissions and the emissions from power plants fired with fossil fuels is decreasing.

The Panel did not review the complementary industrial research, but wishes to endorse the maintenance of excellence in combustion research with strong ties to industry, a collaboration that has historically led to products that compete on the international market.

Nuclear fusion

Besides the renewable energy forms, nuclear fusion is widely recognised as one of the few energy options for the future. It has the potential of providing energy for at least thousands of years: the primary fuels are abundant and widely available. Moreover, fusion is well suited to base-load electricity generation and has inherent advantages with respect to safety and the environment. In June 2005, the EU and five partner countries (China, South Korea, Japan, Russia and USA; India has since joined) decided to realise jointly the ITER project in Cadarache, France. This unique physics experiment, which will also incorporate important technological developments, represents the accumulation of research and development over several decades. It will for the first time produce a burning fusion plasma, i.e. one that produces considerably more power via fusion reaction (deuterium-tritium) than that which is required to heat the plasma, and thus demonstrate the feasibility of fusion as a future power source. Fusion is not, however, expected to make a contribution to energy supply in the short term: the step after ITER – the construction of a demonstration fusion power plant – is unlikely to be undertaken before the period 2025–2030.

Fusion research in the EU Member States is integrated into, and supported financially by, the European fusion programme that is administered under the EURATOM Treaty. In Finland, the so-called EURATOM-Tekes Association was established in 1995 and has a total budget of about 3.5 M€, some 20% of which comes from EURATOM and 80% from Tekes. It contains fusion research units at VTT, TKK, TUT, LUT and UH (University of Helsinki), with a total manpower budget of about 35 professional person-years and headed by a senior researcher from VTT. The physics programme (mainly TKK and VTT Energy and Pulp & Paper, but also UH), making up about one-third of the total, concentrates on key areas of high temperature plasma physics, such as heat and particle transport, MHD physics, plasma edge, plasma heating and plasma-wall interactions. When the Association was founded, it was decided not to build a Finnish fusion experiment, but rather to work on existing facilities in other countries, a strategy which has definitely paid off. The Finnish participation in the joint European Tokamak experiment JET in Culham (UK) and in the ASDEX Upgrade experiment in Garching (Germany) has resulted in work of the very highest standard. The theory and modelling units have an international reputation, not only in the study of fast ions and transport, but also in the simulation of edge processes and plasma-wall interactions. The technology programme, making up about two-thirds of the total, is centred on VTT with important contributions from TKK, TUT and LUT in close collaboration with Finnish industry. Highlights include multi-metal in-vessel components and joining technology, in situ materials testing and characterisation under neutron irradiation, beam welding and welding/cutting robotics, superconductor testing and remote handling. This active involvement in fusion technology with industrial participation will put Finnish industry in a good position to compete for ITER contracts. The EURATOM-Tekes Association is also preparing itself well for ITER in physics, where it will presumably specialise in plasma edge and plasma-wall interactions.

Fuel cells and hydrogen, solar

There is a small but strong fuel cell effort at VTT cooperating with units at TKK and aiming at developing a research infrastructure to support fuel cell activities in industry (in terms of resources fuel cells and hydrogen technology make up about 2% of the total energy budget at VTT). Topics include polymer electrolyte membrane fuel cells (PEMFC), micro fuel cells and solid oxide fuel cells (SOFC). The work receives support from the EU and the units are strongly networked internationally. One of the TKK units has developed a small alkaline fuel cell marketed by a spin-off company. Another TKK unit specialises in studying electrochemical processes and transport in PEMFC. VTT is also developing methods for the production of hydrogen and hydrogen-rich fuels for fuel cells by gasification and advanced gas cleaning. It also participates in an international project on the use of hydrogen in transportation.

Despite the high standard of the work being done in this area in Finland and the level of cooperation between the units concerned, the Panel feels that the effort may be sub-critical in size and will probably need strengthening in coming years. Even if the widespread application of fuel cells in transportation does not come about as quickly as originally anticipated, stationary applications could increase considerably.

Understandably perhaps for a Nordic country, there is only a very low level of activity in solar energy conversion. One group at TKK specialises in materials questions, namely, on ageing and degradation issues in photoactive layers (both for solar thermal and photovoltaic applications) as well as in nanostructured electrochemical solar cells. Another group at TUT studies the photochemistry in organic photosensitive materials and heads a project entitled Organic Solar Cell. The work at VTT is only a "keep-in-touch" effort. The Panel accepts that Finnish priorities in energy research lie elsewhere.

Bioenergy

Among the options to increase the share of renewable energy sources in EU energy supply the White Paper (European Commission 1997) identifies bioenergy as a major contributor: Of the total projected increase of renewable energy sources of 4.3 EJ/a between 1995 and 2010, bioenergy is expected to contribute 3.5 EJ/a. Bioenergy can replace fossil fuels in all end-use sectors, in particular in the transportation sector, where biofuels are the only short-term alternative to fossil fuels.

With the high share of forests in the land area of Finland bioenergy is given special attention in Finnish energy policy. A major driver is the pulp and paper industry, whose energy demand can ideally be met by using biomass residues from its processes. Therefore, corresponding R&D is performed by most of the visited units. VTT with its Knowledge Cluster Energy and Pulp&Paper supported by activities in other clusters (e.g. Biotechnology) probably has the largest capacity in bioenergy research concentrated in a single organisation worldwide. Together with the capacities at the universities, this makes Finland a major contributor to the global effort on the development of bioenergy technologies.

Research activities cover the entire process chain: biomass residues from forestry and wood industry operations; feedstock pre-processing; conversion to solid, gaseous and liquid biofuels; as well as economic and environmental issues associated with the use of bioenergy. Results from research work performed for industry have led to technologies for the production of heat and power that have reached commercial status in many cases: Large scale combustion (see above) and gasification plants are operating successfully. The considerable challenge resulting from the need to find alternatives to fossil-based transportation fuels has been fully recognised by Finnish R&D units. However, the complexity of the processes involved to produce so called second generation biofuels (biodiesel from plant oil and ethanol from sugar and starch crops being the first generation) calls for a coordinated effort of all units having partial know-how. It may be expected that the ongoing effort to design a national energy programme will lead to such coordination between the funding agencies on one side and the research groups on the other. Worldwide efforts under the heading "Biorefinery" have their representation in Finland with a number of initiatives that yet need to be coordinated internally and with the EU initiatives, e.g. the emerging European Technology Platforms related to liquid biofuels. A recent EU conference on biorefinery research was hosted by Finland, which demonstrates the high standing of Finnish R&D in this area.

International cooperation plays an important role in bioenergy research: Finnish groups are well represented in the Research Network of the International Energy Agency (IEA Bioenergy) and in the EU Framework Programme. VTT is coordinating the EU Network of Excellence on "Overcoming the Barriers to Bioenergy" with the mission of combining the capacities of eight leading European bioenergy research organisations.

As mentioned elsewhere in this report, concentration of efforts seems to be a general need in most of the sectors of Finnish energy R&D. Since the topics of bioenergy R&D seem to be scattered by nature due to the complexity of systems, there is an even stronger need for coordination and perhaps concentration of capacities. The tendency to distribute capacities in the regions, possibly caused by the perception that biomass supply is distributed and thus concepts for its utilisation also need to be developed in a distributed manner, is counteracting the required concentration.

3.2 Research resources and environment

3.2.1 Research personnel and staffing

With some notable exceptions, the typical structure of an evaluated research unit comprised one or more professors, one or more postdoctoral researchers, several doctoral students, and modest technical (e.g. laboratory technicians) and administrative support staff. Few units had a team of experienced, mid-career or more senior, research staff below the professorial level.

One problem encountered during almost every site visit was the missing senior researcher level, generally explained by a lack of funds. But it became clear that the university-based units have a high degree of freedom in their use of budgetary funds from their host universities and, the Panel assumes, in the precise use of externally generated contract income. It may be the case that these budgetary funds, and/or external project research income, which could be used to employ more staff at more senior levels, is instead spent on funding temporary research work for a higher number of more economical but much less experienced people (including master's and doctoral students). Yet, in practice, given the competing administrative, supervisory and teaching loads on professors, such mid-career and more senior staff members are often the most research-productive members of a unit. They are also capable of leading, and developing significant sub-programmes of research, and supervising doctoral students. The Panel understands that most research staff are primarily funded by a succession of short-term contracts. Yet, this mode of funding provides no adequate basis for developing the careers of much needed senior staff.

Based on the Panel's experience of universities in some other countries, there could be a risk of externally generated contract research income (e.g. from industry) being priced, incorrectly, at too low a level. This may be because competitive advantage could be obtained by low-cost bids for such research contracts. In addition, low-cost bids may derive from a failure by units and universities to identify, and include, all appropriate overhead costs required to charge contracts at full economic costs. These dangers are ever present in the highly competitive market for externally funded contract research. Such pressures would also tend to favour the use of more economical, less experienced staff and doctoral students.

If the Panel's understanding of this basic staffing model is correct, then the Panel fears it may have at least five regrettable consequences in terms of scientific quality, the accumulation of research experience, academic publications and doctoral studies supervision. The first is a lack of continuity and of a critical mass of accumulated research experience in the conduct of individual research topics. The second is that this system (incorrectly, in the Panel's view) provides 'perverse incentives' for professors to maintain a large number of less qualified, and less experienced, staff and doctoral students – rather than to advance deserving, productive staff into more financially-rewarding and secure research posts. Third, this could mean there is a lack of quality and experience in the supervision of doctoral students (as professors' capacity is greatly limited). Fourth, this model reduces any incentives for professors to shorten the very long period required to obtain a doctoral degree in Finland. Finally, the use of doctoral students for a succession of research projects means that these students do not (and cannot) devote enough time to writing up such project research results for publication in internationally refereed journals – given the high opportunity cost in terms of struggling to complete their doctoral studies.

The Panel recommends that urgent attention be given to establishing a much larger number of experienced, mid-career and senior researchers. More permanent funding arrangements should be put in place for the most research-productive staff. The Panel's views (and statistical evidence) on the long doctoral degree completion times in Finland are provided in another section below. Care should be taken in establishing positions that have clear career paths, with parameters for performance and promotion.

3.2.2 Researcher mobility

The Panel was struck by the comparatively high proportion of unit staff that had undertaken undergraduate and postgraduate training at the same unit or host university in which they are now working. Few had been trained or spent some formative postdoctoral research time at universities outside Finland. Further, comparatively few research employees had been recruited from abroad (perhaps because of language skills); taken together, these characteristics provide little opportunity for genetic diversity, or for cross-fertilisation of ideas. Researcher mobility should be encouraged, both from within and outside Finland, by means of a larger number of competitively awarded travel and visiting fellowships. This should not just be at the professorial level. Emphasis should be on Finnish scientists travelling abroad rather than on an extensive visitor programme, thus enhancing the existing sabbatical system of the Academy of Finland.

3.2.3 Number of PhDs and degree completion times

The Panel was also struck by the long time required to complete a doctoral thesis. In some instances, doctoral candidates received their degrees at the age of 45–55. The Panel is conscious that doctoral training traditions vary significantly between countries. Even so, a swift move to encourage much earlier completion of doctoral training is recommended – say by 30–35 years of age, or even earlier.

One solution to complete the doctoral training earlier is the Finnish graduate school system established in 1995, with financing from the Ministry of Education and the Academy of Finland. As the Panel was told, a key objective is to assure the quality of graduate education, shorten the time it takes doctoral students to write their dissertations and thus lower the age at which doctoral candidates defend their dissertations. The system has been expanded gradually, and the number of schools has doubled from the original. At the beginning of 2006 the system comprises 124 graduate schools. Altogether over 4,000 graduate students are working full-time on their doctoral dissertations in graduate schools.

The Graduate School for Energy Science and Technology at TKK focuses on sustainable energy solutions. The school's main fields of research are renewable energy resources, energy technology of the future, energy technology materials, modelling energy systems and energy resources in Finland, especially bioenergy.

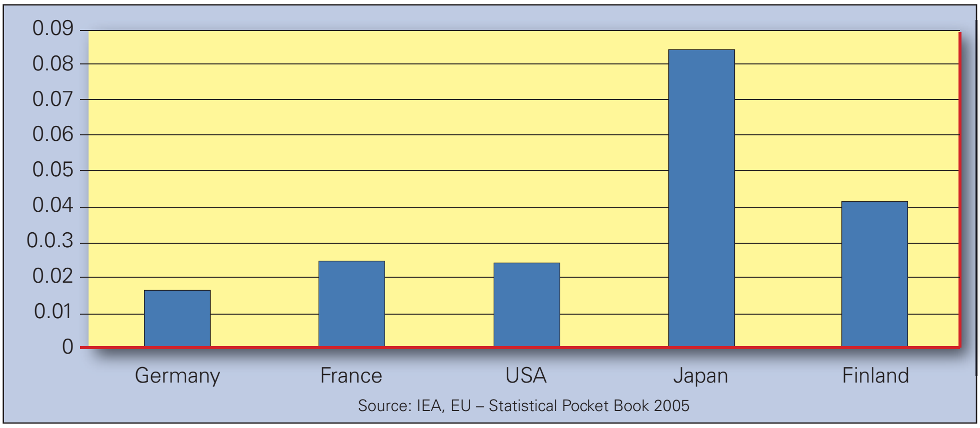
The Panel recommends also that the Academy should fund 3–4-year posts for all postgraduates – not only for those participating in a graduate school (on a competitive basis, as in the UK) – thus (i) greatly shortening the time to PhD and (ii) avoiding the need for doctoral students to be financed by this succession of short research contracts (sometimes on topics not related to their own PhDs).

In several cases, the Panel was concerned to learn that PhD theses had not – or could not – be published because the underlying research had been funded from industrial sources and the results included commercially confidential information. The rule that a PhD thesis must be published constitutes a problem in those cases where an industrial sponsor of the research wishes to keep the results out of the public domain. This restriction on publication can prevent doctoral candidates from completing their degree. The Panel suggests that the Academy undertake a quick inquiry to establish the extent to which this is a cause for concern. If it is, the Academy should identify ways of resolving it satisfactorily and speedily by means of a guidance note for universities and industrial sponsors of research. In some other countries (e.g. Austria) a university can fully complete the degree process but, if genuinely necessary after careful appraisal of the circumstances, keep a thesis locked away for a limited period (e.g. 5 years), allowing the company exclusive access to the results during this period. An alternative model is one followed by a number of US universities to delay publication for a period sufficient to all the sponsors of the research to file a patent disclosure, a period of no longer than six months.

3.2.4 Funding and Infrastructure

It is generally recognised among experts that the problems facing mankind in the provision of energy – the environment, finite fossil fuel resources, increasing demand and security of supply – are very serious and should be giving rise to grave concern at the political level, in the media and in the public at large. The need to find and exploit new, sustainable energy forms and to improve the efficiency of production, transport and conversion of existing energy forms should be readily apparent. Unfortunately, however, the seriousness of the problem has not been recognised and, above all, a sense of urgency seems to be lacking. In particular, it has not been recognised that one of the answers – perhaps the only answer we have at present – is to put more resources into both basic and applied energy research. The low priority given to energy research (approx. 1.6% of all expenditure on R&D in EU Member States) is wholly incommensurate with the magnitude of the problem, and indeed with the threat to our civilisation. Having made this very clear statement, the Panel would like to point out, however, that in international comparison Finland does reasonably well at present. Figure 9 shows that government spending on energy R&D (as a percentage of GDP) is higher in Finland than in Germany, France and the US, although it is substantially lower than in Japan. But Finland could still do more. It is a country widely respected for its recent achievements in technology and its strong economic performance. Finland could set an example to the rest of the world and institute a new, very generously funded programme in basic and applied energy research (of course compatible with its particular needs).

Figure 3. Expenditure on energy research as a percentage of GDP in 2004 (IEA, EU Statistical Pocket Book 2005)



The Panel was impressed with the quality of most of the general university accommodation it saw. Given the shortage of time for site visits, most of our discussions with units were held in their meeting rooms. We understand the reason for this normally high quality of provision is that universities rent their buildings from a publicly-owned company Senate Properties, which is responsible for managing, developing and letting the property assets of the Finnish state, which is responsible for the construction and regular maintenance of these buildings. On occasion, the Panel did visit research laboratories and testing facilities. Generally, these were well equipped, considered at least as good as much equivalent provision at similar universities elsewhere in the EU. The Panel learnt that research facilities and other capital equipment specifically required for research were funded by the Ministry of Education, and by competitive funding allocations for such resources from university budgets. Leading-edge research that is excellent at the EU or global levels requires leading-edge facilities. In particular, excellent research facilities should be provided to the most productive units, possibly through competitive solicitations for equipment grants.

3.2.5 Unit scale and critical mass

Several units appeared to the Panel to be sub-critical in scale in terms of the capability to undertake a sufficiently wide and vibrant research agenda; to retain or to recruit sufficient mid-career research staff, visiting fellows and doctoral students; to permit exchanges of staff elsewhere in Finland or overseas; and to justify the maintenance of adequate journal holdings and other key library resources.

Finland has 20 universities, many of them with engineering departments. This probably is far more than most other countries have, in relation to their population. The situation of sub-critical units might be a consequence of the following thinking at the engineering departments: Energy is an attractive problem and the outside world expects us – as engineers – to work on solving the problem. The researchers establish a curriculum and start research projects, which they see as important and for which they try to get outside money. The funding agencies feel a certain obligation to support these initiatives, after all the capacities are there, and in most cases only the additional costs have to be funded. The absence of a general energy research programme, which would be a filter for the research proposals, and the limited cooperation/coordination between the universities have led to the current situation. So, reconfiguring the university-based research capacity is a very necessary action.

3.3 Cooperation

3.3.1 Cooperation within and between universities

Energy-related research covers a very broad spectrum and is sometimes, but not always, conducted most fruitfully in interdisciplinary groups, or in close collaboration with units whose disciplinary skills can complement and reinforce each other. The Panel formed the view that some universities are actively encouraging close cooperation between units at the same university undertaking energy-related research. In other cases, the extent of intra-university cross-unit contact was astonishingly almost non-existent. As examples, the Panel formed the following illustrative, rather than comprehensive, views about some rather different approaches:

- *Helsinki University of Technology (TKK)*: Despite the fact that energy research is seen as a cross-cutting issue, there seems to be a lack of coordination of the eight units undertaking energy-related research at TKK, both across these departments and across several laboratories within the departments. As a result, no effective opportunity has been taken to exploit all potential synergies. The Panel also notes that there are a further seven units involved in some way in energy research at the TKK (including one undertaking energy systems analysis at the Department of Engineering Physics and Mathematics) which are not included in this evaluation. An inter-departmental centre for energy technology does exist and has been charged with the task of developing alternatives for organising the energy field within TKK. It appears, however, that this effort was not particularly successful and the centre was not put on the Panel's visit schedule. In addition, the existence of a committee was mentioned with the task of informal coordination of energy-related research at TKK. The Panel received no further information about the composition or terms of reference of this committee, but we encourage the university and possibly this committee to enhance such intra-university cooperation as a matter of some urgency.
- *University of Oulu (UO)*: Coordination of energy research is needed between the eight separate laboratories located within the Department of Process and Environmental Engineering. As there appears to be little energy research at the university's other departments, the issue in this example appears essentially to be one of greater intra-departmental coordination.

- *University of Jyväskylä (UJ)*: A Renewable Energy Programme was established in 2003 as a cross-cutting, intra-university initiative. As of yet, this Programme has no permanent identity. It remains, in essence, a virtual centre. It might still be too early to judge whether this is a suitable model; but, as one option, it would appear useful to consider a similar form of organisational initiative at TKK and possibly elsewhere.

Collaboration between *different* universities and their units appeared to vary quite considerably. Whilst some units were deliberately outward-facing, and readily saw the benefits of their effective participation in research networks, others seemed incapable even of dialogue with close research neighbours on the same university site. Ultimately, human interaction is difficult to force on unwilling partners. But, by means of research 'purse strings' and imposing some necessary conditions for successful grant awards, the Academy of Finland and Tekes have significant leverage to encourage (or even require) all applications for research funding to identify ways in which they are seeking to foster collaboration with other relevant units, universities and key end-users of their research (the Panel examines the effectiveness of wider societal interactions in Section 3.3.4 below).

3.3.2 Cooperation with universities outside Finland

The cooperation with universities outside Finland varied greatly between units. Selected examples are provided to show the range of interactions. The nature of the research at TKK places a premium upon effective networking with a wide range of national and international organisations. National cooperation appears modest – effectively achieved by working with research students in other Finnish universities. International cooperation, for example with Russia and South-East Asia, was regarded as excellent, even outstanding, for such a small and non-tenured group. VTT has a range of collaborations, commensurate with its size, across several fields with CEA and TNO; in nuclear energy with IRSN, Halden, CEA and EPRI; in renewable and conventional fuels with ECN, NREL, SLU, SINTEF, AIST and IGES; and with major European bioenergy research units through its leadership in the Bioenergy Network of Excellence organised by the European Commission, involving eight major national European centres. LUT's participation in international cooperation is quite extensive, including active participation in the International Energy Agency's Bioenergy Task 40, and well-established linkages with several research institutions in Russia. The Laboratory of Energy Engineering and Environmental Protection at TKK has provided annual courses in its core areas for 30 to 70 participants, with a strong international presence mainly from the Nordic and Baltic countries. The large research teams at TKK, ÅA and TUT have comparable extensive international networks and exchanges. Other units showed no evidence of interaction with international organisations; as can be seen from Table 12, five units had no overseas visits.

A number of the units interacted, quite understandably, with research institutions in their close proximity: Russia, the Nordic and Baltic countries and the EU. These interactions included a healthy number of joint research programmes and joint courses. Some units had contacts with the US and China; however, these could be strengthened. Senior members of the Finnish energy community are very well represented on editorial boards, thesis review committees, and in presenting invited lectures. Encouragement should be provided for broader involvement of all research units in effective networking with a wide range of national and international organisations.

3.3.3 Effective research dissemination

With very few exceptions, and unlike common practice elsewhere, the Panel did not receive unit-specific research brochures at most of the units it visited in Finland. Such simple and inexpensive brochures provide opportunities to highlight the main research themes and projects under way in a unit, and to list full contact details of all staff responsible for leading each project. If kept up-to-date, these brochures prove most useful to visitors, in securing better communication with academics elsewhere, and with industry and other end-users of research. In the Panel's view such brochures are also invaluable at conferences, and assist participation in collaborative research programmes in the EU and elsewhere. Similarly, attention needs to be paid to ensuring that unit web sites provide up-to-date information on research in progress (with project staff contact details), as well as on completed work.

3.3.4 Interaction between research and society

The interaction with society by the research units takes many forms: contribution to education, research addressing national and societal priorities, service on professional policy bodies and general outreach to Finnish society.

Education: All units, with the exception of VTT and VATT because of their different mission, recognised the importance of providing manpower to the energy industry and have supplied graduates prepared for the challenges of supplying Finnish energy needs. In total, 169 doctoral graduates were produced during the period reviewed. In addition, several of the units developed specialised Master's degree programmes, undertaken in cooperation with industrial companies, to provide skilled engineers well-informed in the needs of specific industry sectors, for example renewable energy and power plant operation.

Research: The research priorities were in general well aligned with national priorities of reducing dependence on fossil fuel, providing a reliable electrical infrastructure, and supporting export industries. The research programmes, practically without exception, involved strong collaboration with industry, and, very significantly, major financial support from industry. The programmes have had outputs of direct value to industry in terms of addressing specific industry needs, additional to that of providing well-qualified graduates and specialised courses. The breadth of industrial outreach is impressive, with extensive interactions set up with different industry sectors: Demonstration sites have been set up in renewable energy in Central Finland through extensive cooperation with companies, research institutes and regional municipalities; and the programmes on safety and operations in the nuclear industry have contributed to Finland's nuclear industry having unparalleled plant availability. Problems of the electrical power industry have been addressed through power plant optimisation; programmes in electrical machines that are of relevance to efficient energy conversion and usage; and research services in specialised high-voltage laboratories. Problems of biomass production and utilisation of value to both the pulp and paper industries and internal combustion engines are being addressed. Research programmes on fluidised bed technologies, a historical national strength, are addressing problems of waste destruction, energy production and CO2 sequestration of importance to the Finnish economy. Problems of air pollution through transportation are investigated extensively in vehicle and engine testing laboratories. Measures of the success of these interactions of the universities and VTT with industry are provided by the spin-off companies, 1,100 refereed publications and 174 patents.

Providing policy advice: Some of the units have targeted policy questions, and a greater number of the senior researchers have provided technical and policy advice to Finnish government agencies, Parliament and the EU. Two of the major efforts relating to policy were targeted at nuclear energy and climate change. VTT was called upon to apply its great competence to support the development of national policy and strategic planning as well as carry out the R&D work resulting from its engagements in policy and strategic planning. This illustrates a key dilemma confronting public R&D funding: should the programmes be carried out in a long-term partnership with one (or a few) preferred partners to assure continuity and utilise the accumulated expertise; or should there be some degree of competition at the expense of continuity? The activities related to global climate policy research have been conducted by Turku School of Economics and Business Administration (TuKK) and the Government Institute for Economic Research (VATT). There is clearly a high degree of relevance for society from the very nature of the work. Potentially, the research programme of these units, particularly VATT, can – by assisting in establishing and evaluating national energy policies – have direct effect on government thinking and legislation. The inclusion of sustainability aspects into their economic models and their incorporation into government policy is of potentially major value.

Public outreach: The efforts in the popular media by VTT and the universities were commendably high. These were reflected by many units taking part in national debates on energy issues, providing information for parliamentary and governmental decision-making, and communicating their technical contribution to society through the print and electronic media. The fusion team has an impressive record in promoting public awareness of fusion research. Their activities encompass articles in newspapers and magazines, radio and TV appearances as well as discussions with politicians. The fission team has also been active in this respect but its small size has limited its role. Activities of several of the units working on renewable energy have contributed to changing the negative public image of chemical technology and making the subject more attractive to young people. As a consequence, the public has an increasing appreciation for Finland's needs for power and chemicals from domestic renewable resources. The importance of securing a sustainable future energy supply is widely recognised by Finnish society. The high acceptance by both public bodies and society at large of the importance of energy and energy research has been well served by these efforts.

3.4 Towards shaping a national research agenda – 'bottom-up' and 'top-down'

Universities are independent organisations, and research agendas are often shaped bottom-up by experienced researchers who are active in their field and aware of its leading edges in national and global terms. Some of these leading edges may be in applied research – identified by close collaboration with industry or other end-users of research. Many other leading edges exist in more fundamental, basic research. A ‘blue skies’ component is essential in any lively, university-based research portfolio.

But universities are also heavily dependent on public funding. Thus, national policy interests also play an important role in shaping (and, crucially, in funding) energy-related research agendas in a top-down manner. These may be influenced inter alia by factors such as: (i) natural resource endowments (e.g. fossil fuel, forest and hydro-electric power assets); (ii) comparative industrial advantages (e.g. in power engineering, paper or boiler technology); (iii) the existing and anticipated energy mix (e.g. dependence on nuclear power); and (iv) longer-term, national strategies to focus on one or more novel technologies (e.g. bioenergy complexes, fuel cells, hydrogen, photovoltaics and wind power). Careful, well-informed and evidence-based judgements are required to shape energy R&D strategies, and consensus must be built for them – particularly amongst university and industrial circles.

Mechanisms are needed to shape university-based research and postgraduate training towards nationally agreed objectives, whilst preserving the scope for wilful individuals to follow truly basic research objectives in areas with no immediate or apparent relevance. Such mechanisms, in Finland and elsewhere, include national scientific academies. But, it is not sufficient merely to identify national research priorities and then to use funding from the Academy of Finland to steer universities towards these high-priority topics. The national scientific effort may need to be shaped more proactively. In the specific case of energy research, there are strong drivers for this process: pressing problems of climate change, fossil fuel supply, increasing global demand and security of supply. Therefore, Finland should institute a programme of basic and applied energy research (Energy Research Programme). Priorities and goals in the Programme should be defined based on the needs of national energy policy and of industry and be supported by coordinated energy systems research. It should also contain a European perspective by accounting for the R&D needs specified in the Strategic Research Agendas defined by the energy related European Technology Platforms. The Programme should provide top-down guidance for the selection of topics by research units and also give orientation for basic research and for shaping postgraduate training. The implementation of the Energy Research Programme should make use of the flexibility and continuity provided by VTT supplemented by the university-based capacity.

Some Panel members formed the view that the current university research effort is quite highly fragmented, and that, in some cases, it embraces a rather arbitrary portfolio of quite small projects. In the more applied research areas, these projects may or not meet the specific needs of industry and technology policy. This perception again reinforces the Panel’s earlier views on the need for the Academy, Tekes, ministries and industry to consider what additional mechanisms might be needed to shape at least some university-based research and postgraduate training towards nationally agreed objectives. The role of VTT is also important in this context, given its large share of the overall effort. However, it may be difficult to apply the high competence at VTT in public strategy planning because of a scope for a conflict of interest seen by public programme planning (e.g. Tekes, if VTT proposed R&D actions which it later applied to carry out itself, e.g. the biorefinery strategy – developed by both VTT and Tekes). Whilst the Panel is thus suggesting somewhat greater shaping of the research effort, in more applied areas, it certainly does not wish to be too prescriptive about the more fundamental, basic research agenda of universities.

Appendix a:
Members of the Evaluation Panel

GÖRAN ANDERSSON
Professor, Power Systems Laboratory, ETH, Switzerland

Göran Andersson was born in Malmö, Sweden. He obtained his M.Sc and PhD degree from the University of Lund in 1975 and 1980, respectively. In 1980 he joined ASEA:s, now ABB, HVDC division in Ludvika, Sweden, and in 1986 he was appointed full professor in electric power systems at the Royal Institute of Technology (KTH), Stockholm, Sweden. Since 2000 he is full professor in electric power systems at the Swiss Federal Institute of Technology (ETH), Zürich, where he heads the powers systems laboratory. His research interests are in power system analysis and control in particular power systems dynamics and control involving HVDC and other power electronics based equipment.

Göran Andersson is Fellow of the Institute of Electrical and Electronic Engineers (IEEE), member of the Royal Swedish Academy of Sciences, and member of the Royal Swedish Academy of Engineering Sciences. He is Editor-in-Chief of IEE Proceedings Generation, Transmission and Generation.

ALEXANDER M. BRADSHAW
Professor, Max-Planck-Institut für Plasmaphysik, Germany

Alexander Bradshaw studied chemistry at the University of London where he obtained his PhD in 1969. From 1980 to 1998 he was Scientific Member and Head of the Department of Surface Physics at the Fritz-Haber Institute of the Max-Planck Society in Berlin as well as 1981 to 1989 (with an intermission) Scientific Director of the synchrotron radiation source BESSY. Bradshaw is a member of acatech (the German Academy of Engineering) and the Berlin-Brandenburg and Leopoldina Academies of Science as well as Honorary Professor of Physics at the Technical Universities of Berlin and Munich. During 1998-2000 he was President of the German Physical Society (DPG). The results of his research in surface physics, molecular photoionisation and synchrotron radiation instrumentation have resulted in over 400 publications and several awards. He co-founded the open access journal „New Journal of Physics in 1998 and initiated the German „Jahr der Physik“ in 2000. He received the Public Understanding of Physics Prize of the European Physical Society in 2001, the „Bundesverdienstkreuz“ in 2002 and an Honorary DSc from the University of London in 2005. Since 1999 he has been Scientific Director of the Max-Planck Institute for Plasma Physics and chairs the German nuclear fusion programme.

JOHN CHESSHIRE
Honorary Professor SPRU (Science and Technology Policy Research)
University of Sussex, United Kingdom

John Chesshire is an economist (BA Econ, Durham, and MA Econ, Sussex). He is a former Fellow & then Professorial Fellow of SPRU, University of Sussex (1970-71 & 1974-2000). Economics Department, TUC, 1971-74. Associate Director of UK Economic and Social Research Council's designated national Centre for Science, Technology, Energy and Environment Policy and Head of the SPRU Energy Programme (1986-97). Main research interests include: (i) energy policy; (ii) energy demand analysis and energy efficiency policy; (iii) energy pricing and investment; (iv) electricity and gas liberalisation and regulation; and (v) energy R&D and technology policy. From 2000, Honorary Professor, SPRU; and policy adviser to UK public agencies, Government departments and several international institutions. Now Chair of the Advisory Board, Sussex Energy Group, SPRU, University of Sussex. Also a Visiting Professor, City University; and Associate Fellow, Environmental Change Institute, University of Oxford. Regular teaching on postgraduate courses and member of advisory boards and PhD panels at numerous UK/EU universities. An Editorial Board Member of *The Business Economist, Energy Economics, Energy and Environment and Utilities Policy*. Currently a Member of the UK Government's Sustainable Energy Policy Advisory Board and Chairman, Energy Efficiency Partnership for Homes. He was Specialist Adviser on energy matters to several House of Commons Select Committees over 22 years; and has advised many national and international agencies. Fellow of the Royal Society of Arts. Council Member and Academic Vice-President, 1995-2005, of the British Institute of Energy Economics. Companion, Melchett Medallist, Fellow, and past President of the UK Institute of Energy. Appointed OBE by HM The Queen in 2003.

ESTEBAN CHORNET
Professor, University of Sherbrooke, Canada

Esteban Chornet graduated in 1966 in Ind. Eng. (ETSIIB, Barcelona, Spain). In 1971 he received his Ph.D. in Chem. Eng. (Lehigh). His academic career has been as Professor of Chem. Eng. at the Université de Sherbrooke. Since 1993 he has been also affiliated with the National Renewable Energy Laboratory (NREL), Colorado. He is a specialist in reaction engineering with specific interest in bioenergy and biofuels. He has directed 73 graduate thesis (19 Ph.D.), 183 refereed publications, 15 chapters/sections in books, 21 patents and numerous presentations in national and international conferences. He is co-founder of Kemestrie holding, a spin-off of the Université of Sherbrooke, in charge of technology transfer from his research lab. He is CTO of Enerkem, an operating company, spun out by Kemestrie in 2000, dedicated to the energy-environment interface. Among his awards: the Steacie Fellowship Award, by the Government of Canada and the Prix Lionel Boulet, the highest technology prize awarded by the Government of Quebec. He has also received prizes as pedagogue. He is a Fellow of the Chemical Institute of Canada, of the Canadian Academy of Engineering; and of the Royal Society (Canada). He has acted in numerous advisory boards. Among them: Group Leader of the Engineering Grant

Committees of the National Science and Engineering Research Council of Canada (NSERC); member of the National Advisory Board in Energy Science and Technology (NABEST) of the Government of Canada; and member of the Scientific Council of the Fonds québecois de recherches sur la nature et les technologies (FQRNT).

TRUC-NAM DINH
Professor, Nuclear Power Safety, School of Engineering Science
Royal Institute of Technology (KTH), Stockholm, Sweden

Truc-Nam Dinh received his MSc (Thermophysics) in 1988, PhD (Nuclear Engineering) in 1991 and D.Sc (habilitation degree) in 1994, all from Moscow Power Engineering Institute, a Technical University in Moscow, Russia. He was a group leader and head of "Numerical Analysis of Reactor Accident Laboratory" in the Electrogorsk Research and Engineering Center during 1991-1993. During the period 1994-1999, he was a research scholar, head of computational and analysis group, head of Severe Accident Research Laboratory and Associate Professor (Docent) at the Division of Nuclear Power Safety of the Royal Institute of Technology (KTH) in Stockholm, Sweden. During the period 1999-2005, Dr. Dinh was Adjunct Associate Professor at the University of California, Santa Barbara (UCSB), where he taught courses for mechanical and environment engineering and worked as Associate Director at the Center for Risk Studies and Safety. His research areas include nuclear reactor thermal hydraulics and safety, severe accident risk assessment and management, multiphase flow and heat transfer, computational fluid dynamics. Dr. Dinh received Best Paper Awards from American Nuclear Society (ANS-Thermalhyraulics), American Institute of Aeronautics and Astronautics (AIAA-Thermophysics). He is AIAA Associate Fellow and the 2004 recipient of the ANS Young Member Engineering Achievement Award.

ADEL SAROFIM
Presidential Professor, Department of Chemical Engineering
University of Utah, USA

Adel Sarofim received his BA in Chemistry from the University of Oxford and his S. M. and Sc.D. degrees in Chemical Engineering from MIT. He held various faculty positions in the Chemical Engineering Department at MIT from 1961 to 1996, most recently as the Lammot du Pont Professor from 1989-1996. He has also held visiting professorships at Sheffield University, the University of Naples; and Caltec. Dr. Sarofim is the author and co-author of over 200 papers on the subjects of radiative heat transfer, furnace design, circulation patterns in glass melts, the freeze process for desalination, nitric oxide formation in combustion systems, combustion generated aerosols, soot and polycyclic aromatic hydrocarbon formation, and the characterization of carbon structure and reactivity. He has graduated over 70 doctoral students and supervised over 40 postdoctoral fellows. He has received several awards including the Egerton Gold Medal of the Combustion Institute, Ahlström Prize of the Finnish Academies of Technology and the Lowry Award of the U.S. DOE. He is a member of the U.S. National Academy of Engineering. He has served on several editorial boards and numerous advisory committees to academia and government.

JOSEF SPITZER
Professor, Joanneum Research, Graz, Austria

Josef Spitzer completed his undergraduate study in Mechanical Engineering at the Technical University of Graz, Austria, during 1961–1967; thereafter during 1967–1971 he obtained Master of Science and Doctor of Philosophy degrees in Nuclear Engineering at the University of New Mexico (USA). He has worked in nuclear reactor design (Interatom Bergisch Gladbach, Germany, 1971–1975). Between 1975 and 1982 he was head of the Department of Energy Technologies at Battelle Institute e.V. Frankfurt in Germany. From 1982 onwards, he has been the head of the Institute of Energy Research at Joanneum Research Graz, Austria. Since 2001 he also holds an Associate Professorship in Energy Economics at the Technical University Graz. He has held several international positions within the energy sector. Since 1994 he has been Austrian delegate in the Executive Committee of the bioenergy research network of the International Energy Agency (IEA Bioenergy), and chairman of the Committee for 1999 – 2001. Beginning in 2006 he is member of the Advisory Group on Energy for the 7th Research Framework Programme of the European Commission.

KARI TÖRRÖNEN
Professor, Director European Commission, Joint Research Centre, Institute for Energy

Kari Törrönen received his Dipl.Eng. and D.Tech. in Physical Metallurgy from the Helsinki University of Technology. He started his career 1970 in Reactor Materials Group at the Ministry of Trade and Industry in Finland and was transferred to the Technical Research Centre of Finland (VTT) in 1974, where he held various research and managerial positions. In 1988 Törrönen was nominated as Director (with the title of Professor) of the Metals Laboratory, which in 1993, in restructuring of VTT was renamed Department of Materials and Structural Integrity Research.

In 1995 Törrönen was elected and nominated as the Director of the Institute for Advanced Materials, Joint Research Centre of the European Commission. The technical areas addressed included power production (nuclear, advanced coal fired, renewable), transport, petrochemical, environment protection, as well as health care (especially nuclear medicine).

In 2001 the institute was further focused on issues related to the security of energy supply and to sustainable and safe energy production, and consequently renamed the Institute for Energy. Today the institute activities focus on safety of existing and future innovative nuclear power plants, nuclear waste storage, biomass and waste, hydrogen and fuel cells and energy information evaluation and verification. The institute has a number of state-of-the-art facilities including the High Flux Reactor, Plant Simulation Testing Laboratory, Hydrogen Storage Laboratory and Fuel Cell Testing Laboratory.

Kari Törrönen is author or co-author of about 300 scientific publications and reports, he is/has been a member and chairman of many international committees, most recent one include the Advisory Council of the European Hydrogen and Fuel Cell Technology Platform. He has participated in evaluation teams concerning the U. S.NRC Structural Integrity Programmes in 1998, the National Research Institute of Metals (Japan) in 2000 and PSI (Switzerland) in 2001. In 1987 he was elected as a member of the Academy for Technical Sciences in Finland.

Appendix B: Terms of reference for the panel

1. Organisation

The Research Council for Natural Sciences and Engineering of the Academy of Finland approved the general agenda for the evaluation of this research field during 2006. The Research Council for Natural Sciences and Engineering appointed a Steering Group to lead and support the execution of the evaluation. The evaluation is conducted in co-operation with other organisations providing funding for the field. Those involved are the Funding Agency for Technology and Innovation (TEKES), the Ministry of Trade and Industry, and the Association of Finnish Energy Industries. The Steering Group also has representatives from two enterprises.

The members of the Steering Group are:
Hannu Hänninen, Professor, Member of the Research Council for Natural Sciences and Engineering, Academy of Finland, Chairman of the Steering Group
Jukka Leppälahti, Chief Technology Adviser, TEKES
Sirkka Vilkamo, Industrial Counsellor, Ministry of Trade and Industry
Petra Lundström, Technology Manager, Fortum Corp.
Kari Saviharju, Director, Andritz Corp.
Jari Kostama, Director, Association of Finnish Energy Industries.

The list of invited Evaluation Panel members, the list of evaluation documents to be submitted, and the Terms of Reference have been reviewed and approved by the Steering Group.

2. Evaluation Panel

The external evaluation will be carried out by an independent Panel of experts. The Academy of Finland has invited nine distinguished scientists as Evaluators:
John Chesshire, Professor, SPRU, University of Sussex, UK, Chair of the Panel
Göran Andersson, Professor, Power Systems Laboratory, ETH, Switzerland
Alexander M. Bradshaw, Professor, Max-Planck-Institut für Plasmaphysik, Germany
Esteban Chornet, Professor, University of Sherbrooke, Canada
Nam Dinh, Professor, Royal Institute of Technology (KTH), Sweden
Adel Sarofim, Professor, University of Utah, USA
Josef Spitzer, Professor, Joanneum Research, Austria
Tord Torisson, Professor, Lund University, Sweden *)
Kari Törrönen, Professor, EU-JRC Institute for Energy, The Netherlands *)

*) *Note: Professor Torisson and Professor Törrönen were both not able to participate in the event.*

3. Objectives of the evaluation

A. The objective

The objective is to evaluate energy research in Finland during the period 1999-2005. This includes the evaluation of the scientific quality of the research. The key issues are:

- Strengths, weaknesses and success stories
- Opportunities, challenges and threats
- National and international collaboration
- Available resources
- Utilisation of results
- Research training
- Future objectives of the research groups; and
- Recommendations for improvement at both the unit and general levels.

B. Scope of the evaluation and evaluation criteria

The evaluation includes all research funded from public or private sources. The evaluation includes research units in universities and research institutes (e.g. VTT), identified by the Steering Group. The Steering Group for the evaluation has narrowed the evaluation to include research of energy production and transfer. The research of energy usage will be evaluated if the research unit has undertaken this type of research activity.

The main emphasis is on scientific evaluation. The Panel is asked to evaluate the quality of research of each unit. The central issue is the quality, innovativeness and efficiency of the research as measured by international standards. The Panel should ensure that the evaluation takes into account all of the relevant material available.

The Evaluation Panel is also asked to comment on the following issues:

- The impact of the research (on science, society, and on the unit itself)
- National and international collaboration
- Any other issue the Panel considers important.

For each unit evaluated the Panel is asked to select among themselves one member who will provide a written statement on the opinion of the Panel.

C. General recommendations

The Panel is asked to characterise the evaluated field as a whole and provide recommendations on its future development. In addition to the research itself these recommendations may concern the following:

- Resources (facilities, personnel, economic resources)
- Research network and data management infrastructures
- Education and career policies
- Impact of the field on other research fields and on society in general
- National funding policies and research strategies
- Co-ordination, administration and international relations
- Any other issue the Panel considers important.

The Chair of the Panel is asked to provide a written statement summarising the general recommendations.

4. Site visits and interviews

A sample of researchers will be interviewed during the site visits e.g.:

- Heads of Units (research)
- Senior staff, professors, postdoctoral researchers, visiting foreign scholars etc.

The specific timetable and instructions will be provided by the Evaluation Team in due time.

5. Co-ordination of the evaluation

The evaluation process is operationally co-ordinated by the Evaluation Team set up by the Academy of Finland: Director Susan Linko, Science Adviser Pekka Katila, Science Adviser Outi Oila, Senior Science Adviser Pentti Pulkkinen and Project Officer Henriikka Katila, together with the Co-ordinator Simo Makkonen from Process Vision Corp. The Co-ordinator will assist the Evaluation Panel on site visits and in preparation and editing of the evaluation report. The duties of the Project Officer are to compile the evaluation documents, organise the practical details of the site visits and provide administrative support.

6. Confidentiality of the evaluation

Panel members undertake not to make use of, nor to divulge to third parties, any non-public facts, information, knowledge, documents or other matters communicated to them or brought to their attention in the performance of the evaluation. The evaluation and the ratings are only for official use and are confidential until the final summary evaluation report is published.

7. Evaluation report and publicity

The evaluation report, including the main recommendations, is based on the evaluation criteria defined by the Academy of Finland. The evaluation report will be written and edited by the Panel members with the assistance of the Co-ordinator. Prior to the final editing and publishing, the units of assessment will be able to review the report to correct any factual errors. The evaluation report is confidential and only for official use until publication. The evaluation report will be published in the Publications of the Academy of Finland in both printed and electronic form.

8. Funds

The evaluation is funded completely by the Academy of Finland. The Academy of Finland will pay an expert fee to the Panel members. All travel expenses related to the Panel's visits and accommodation in Finland will be covered or reimbursed by the Academy of Finland.

Helsinki, 12 May 2006
Hannu Hänninen
Chair of the Steering Group
Academy of Finland

Appendix c: Questionnaire (C1) and instructions (C2)

Evaluation of the Energy Research in Finland 1999 - 2005
Submission Form

GENERAL INFORMATION

Organisation	
Department or equivalent	
Address	
Phone	
Internet home page	
Head of the Department	
Phone	
Email	
Contact person for the Evaluation	
Phone	
Email	

Unit's research profile in evaluation context

Research field	(%)
Energy production	
Power plants	
Emission control	
Energy infrastructure	
Energy conversion	
Industrial energy efficiency	
Future energy sources (solar, fuel cells, fusion etc.)	
Energy forms	(%)
Renewable energy	
Non-renewable energy	
Fission energy	
Fusion energy	
Combustion	
Bio-energy	
Hydro power	
Wind energy	
Solar energy	
Peat energy	
Industrial energy efficiency	
Fuel cells	
Electrical	
Other (what ?)	
Total	

1. RESOURCES

1.1 Staff in 1999-2005 (person-months)

	1999	2000	2001	2002	2003	2004	2005	Total
Professors								
Other senior researchers								
Postdoctoral researchers								
Postgraduate students								
Other academic staff								
Visiting researchers and visiting research students								
Total research active staff								
Technical personnel								
Administrative personnel								
Other personnel								

1.2 Research active staff [1]

Name	Task	Academic degree	Period	FTE

1 Staff on December 31, 2005. Personnel includes persons receiving salaries and grants. See instructions for more details.

2. RESEARCH OUTPUT

2.1b Describe the Unit's research (max. 4 pages)

2.2 Number of scientific publications and other outputs 1999-2005

Type of output	Number
1. Articles in refereed international journals	
2. Articles in refereed international edited volumes and conference proceedings	
3. Articles in refereed Finnish scientific journals	
4. Articles in refereed Finnish edited volumes and conference proceedings	
5. Scientific monographs published abroad	
6. Scientific monographs published in Finland	
7. Other scientific publications	
8. Patents	
9. Computer programs and algorithms	
10. Visiting lectures	
11. Radio and television programmes and journals popularising science	
12. Other output	

2.3 Lists of senior researchers' best publications (see 1.2)

2.4 Copies of the Unit's best publications

(append copies of publications, maximum number of publications = number of senior researchers but a minimum of five publications)

3. DOCTORAL TRAINING

3.1 List of doctoral dissertations 1999-2005

Name (family name, given name)	Year of birth	Gender	Topic of dissertation

3.2 Completed doctoral degrees (in order of completion, per year)

Name (family name, given name)	Year of birth	Gender	Year of completing the degree/organisation

3.3 Employment of PhDs

Name	Year of disputation	Present employment (job description, organisation)

4. International cooperation

4.1. Visits abroad (minimum duration of visit: one month)

Name	Target organisation	Country	Topic of the visit	Duration (in months)

4.2. Visits to the Unit (minimum duration of visit: one month)

Name of visitor	Home organisation	Country	Topic of the visit	Duration (in months)

4.3. Short but particularly important visits

Name of visitor	Home organisation	Country	Topic of the visit

4.4. Most important collaborators

Name	Organisation	Country

4.5 Describe the most important outcomes of the visits and collaboration contacts (max. 1 page)

5. Other scientific and societal activities

5.1 Invited presentations in scientific conferences

Name	Topic of presentation	Name and time of the conference

5.2 Memberships in editorial boards of scientific journals

Name	Journal	Period

5.3 Prizes awarded to researchers, honours and scientific positions of trust

Name	Prize, position etc.

5.4 Memberships in committees and in scientific advisory boards of business companies or other similar tasks of no primarily academic nature

Name	Tasks	Period

6. The Unit's self-assessment

6.1a SWOT – evaluation of the Unit's scientific strengths, weaknesses, opportunities and threats (expertise, funding, facilities, organisation; max. 2 pages).

6.1b Benchmarking, evaluate the Unit in relation to its leading scientific competitors (compare funding and results to those of its three leading competitors, opportunities/restrictions; max. 2 pages).

6.2 The Unit's research strategy 2006–2008 (relation to the parent organisation's strategy, priority areas in research, development measures; max 1 page)

6.3 The societal impact of the Unit's activities (max. 1 page)

6.4 Assess the academic and societal need for doctoral training within the Unit's research fields and the Unit's role in doctoral training (max. 1 page).

7. Funding

7.1 The Unit's core and external funding received from the parent organisation.

Source of Funding		1999	2000	2001	2002	2003	2004	2005	Total
Core funding	Budget funding								
	Other								
External funding	Academy of Finland[2]								
	TEKES								
	Ministry of Trade and Industry								
	Other public sources								
	Industry								
	Private foundations								
	EU								
	Other foreign organisations								
Total									

Notes (if applicable)

7.2 Evaluate the role of the Academy of Finland in promoting the scientific and societal impact of research (max. 1 page)

7.3 Evaluate the role of funding awarded by different funding organisations in promoting the scientific and societal impacts of research, excluding funding from the Academy of Finland (max. 1 page)

C2 – Instructions to submission form

1. Staff

1.1 Indicate information on the staff in full time equivalents (FTE). Full time equivalent refers to annual full-time work including paid holidays and other statutory days off. Other holidays, leaves of absence etc. shall be deducted from the calculatory working time.

One person-workday is 8 hours 15 minutes and one person workweek 41 hours 15 minutes effective working time (lunch hours included, 1 hour/day). If the person's working time is less than the norms of normal office hours, the amount of person-work is calculated using the working time norm as divider.

2 See instructions.

Research active staff includes persons who plan, produce and publish new knowledge, theories and methods as well as products and processes based on them and lead research projects. Technical personnel refer to persons working under the supervision of research active staff to carry out projects but who are not involved in the theoretical planning, publishing or other related activities. Administrative personnel refer to persons who take care of administrative tasks related to the research, such as financial and personnel administration or other office duties but who are not normally involved with the technical implementation of the projects.

Persons under the following titles will always be listed in the research active staff:

- Academy Professor (In Finnish: akatemiaprofessori)
- Academy Research Fellow (akatemiatutkija)
- Assistant (assistentti);
- Chief Research Scientist (johtava tutkija;)
- Clinical Teacher (kliininen opettaja, apulaisopettaja;)
- Doctoral Assistant (tohtoriassistentti)
- Group Leader (ryhmänjohtaja)
- Head of Research (tutkimuspäällikkö)
- Laboratory Director (laboratorionjohtaja)
- Postdoctoral Research Fellow (tutkijatohtori)
- Professor (professori)
- Research Professor (tutkimusprofessori)
- Research Director (tutkimusjohtaja)
- Research Lecturer (tutkijalehtori)
- Senior Curators (yli-intendentti)
- Senior Researcher (vanhempi tutkija)
- Specialist Researcher (erikoistutkija)
- University Lecturer (yliopistonlehtori)

Moreover, the following persons should always be included in the research active staff:

a) Postdoctoral researchers
b) Doctoral students (category: Doctoral students) belonging to either of the following groups:

- Persons with at least an MA or MSc (or equivalent) degree who have been employed by the university as full-time researchers or assistant researchers to do doctoral studies for a period of no less than six months.
- Persons with at least an MA or MSc (or equivalent) degree who, for a period of no less than six months, have fulfilled the following two criteria: they a) have been affiliated with the Unit as full-time researchers or assistant researchers to do doctoral studies and b) have been receiving research funding from some other source than another university or research institute.

These groups include, e.g. doctoral students employed by graduate schools.

Doctoral students who do not fulfil either of the above criteria, i.e. who have not been employed by the university and have not been receiving other funding, can also be included in the research active staff for the period they are not holding a post in another university or research institute. The Unit can decide case by case whether to include these doctoral students. It is worth observing that it is not necessarily advisable to include doctoral students who do not have substantial publications from the period 2000-2004.

According to its choice, the Unit can also include other members of the staff in the research active staff, e.g. departmental amanuenses (amanuenssi).

1.2. In case persons duties have changed during the period under review (e.g. from technical personnel to research active staff), indicate the person's both tasks and period according to the format.

2. Scientific publishing

2.1a Estimate of the Unit's research orientation according to fields of science related to this evaluation.

2.1b This question surveys how the research carried out in the Unit has impacted research in its own field(s). Describe the orientation of scientific publishing, most important research results and the role of multidisciplinarity or interdisciplinarity etc. In case the research carried out in the Unit is clearly specialised in the different fields of food sciences, describe each field separately (see also question 6.3).

2.2a List of publications and other outcomes in the order indicated in the summary table, by type of outcome. Regarding each outcome, indicate the name of the author/authors and the outcome.

2.2b In the summary table, calculate the number of each type of outcome in the list during the period under review.

2.3 Each senior researcher shall list five of his/her key publications during the period under review, indicated in the order of quality. Unlike other information, the list may also include manuscripts published in 2005 or manuscripts approved for publication but still unpublished. A copy of the manuscript approved for publication shall be submitted with the other information.

At the end of the publication data, give the impact factor in bold (use only one year). Researchers may if they so wish also give the citation index of their publications. Indicate this citation index as the last information by using the abbreviation CI = number of citations.

References to books should give the names of any editors, place of publication, editor, and year.

Example:

Von Wright A, Bruce A. Genetically modified micro-organisms and their potential effects on human health and nutrition. Trends in Food Science & Technology 2003; 14: 264-276; IF=1.8; CI=2

2.4 For ensuring easy readability do not make the font size smaller when copying publications. The copies of publications shall be two-sided.

3. Doctoral training

3.1 If at least half of the doctoral dissertation has been supervised and done at a research institute, the research institute can also list the doctoral dissertation as its own outcome. In this case indicate also the university where the doctoral dissertation has been presented for approval.

3.2 Indicate only degree-awarding organisations.

3.3 In addition to the name of the organisation, indicate the type of organisation (university, business company, research institute, state, municipality or other).

4. The Unit's collaboration contacts

4.1–4.3: List the visits per year. List the visits of each year by country in the alphabetical order. In Field 1, give other information in accordance with the title except the duration of the visit that is to be indicated in Field 2. The minimum duration of a visit to be indicated is one month. In item Topic of the visit indicate clearly the objective of the visit, for example regarding a post doc period describe what were the content objectives related to the visit.

Item 4.4: Collaborator refers to a person or a research team with whom the cooperation has either generated or is expected to generate within the next three (3) years one of the outcomes indicated in Item 2.2.

4.5. Describe here e.g. key joint publications, researcher training, adoption and use of new technologies or new approaches.

6. The Unit's self-assessment

Self-assessment is an important part of the evaluation. Please answer carefully.

6.1 and 6.2. In addition to strengths and weaknesses it is also important to assess what the present strengths or developable strengths enable in the future and what kinds of threats are related to the weaknesses.

6.3 Describe the Unit's research programme for the next few years, the key research objectives and means to achieve these objectives. What is the role of basic and applied research? Is there need for new knowledge, facilities, is the present level of funding sufficient for attaining the objectives laid down? Do the strategies of the parent organisation and the Unit support each other?

6.4 Describe here how the Unit's research activities and cooperation with other actors in society have promoted the activities of other societal actors. Describe e.g. how the activities have promoted food-processing industry, the activities of SMEs, production and use of new food products, production and use of functional food products, drafting of new regulations and norms, general knowledge of the quality of food products etc.

7. Funding

7.1. Core funding applies to the Unit's budget funding and possible other funding for research awarded by the parent organisation. The funding covers both the salary costs with social charges of the staff and the operational costs which include consumption costs and investment costs for research activities.

7.2 Use of research funding received from external sources, indicated per year. Academy of Finland fellowships should also be involved and counted. Salaries should be counted as 1.33 * gross salary.

7.3 Describe how the funding awarded by the Academy has promoted the scientific and societal impact of the Unit's activities. Scientific impact refers to the contribution of the research carried out by the Unit to the development of the field. Societal impact refers to the ability of the research activities to promote values that are considered as important in society.

7.4 Describe the contribution of the funding awarded by different funding organisations to the scientific and societal impacts.

Appendix D: Execution of the evaluation

The evaluation of Finnish energy research covered 23 units. To conduct the evaluation the Evaluation Team prepared a Self-Evaluation Form that was sent to all units to be evaluated. The units listed in Table 2 submitted their filled-in forms to the Evaluation Team in the beginning of May 2006 and the forms were sent to Evaluators of each unit in advance. In addition the Coordinator provided a preliminary summary of statistics to the Panel on May 29th 2006.

The evaluation was conducted according to the following timetable:

- *January–February 2006: Definition of the field (energy-related research, actors)*
- *February 2006: Appointment of Steering Group*
- *March 2006: Appointment of Evaluation Co-ordinator*
- *March 2006: Appointment of Evaluation Panel*
- *March–April 2006: Definition of evaluation criteria*
- *February–March 2006: Communication to the field*
- *15 March 2006: Initial seminar of energy research evaluation and workshop for the thematic research programme for unit representatives and researchers interested in the programme*
- *March–April 2006: Preparation and submission of evaluation documents by the units*
- *29 May–2 June 2006: Site visits to assess the units*
- *June–September 2006: Preparation of report*
- *October–November 2006: Publication of report*

Appendix E1: Summary of research resources

Tables 1–4

Table 1

Number of total research staff 1999–2005 (ftes, a)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	4.0	4.0	6.5	8.0	65.0	91.5	110.0	289.0
2	50.0	58.5	64.0	68.6	72.3	80.2	83.5	477.1
3	32.0	37.5	40.7	41.3	44.8	55.5	70.5	322.3
4	33.5	21.7	29.9	30.2	29.0	29.0	20.0	193.3
5	15.8	14.4	15.1	14.3	12.7	13.4	10.4	96.0
6	15.7	15.9	17.5	17.5	18.0	19.6	19.2	123.3
7	28.8	27.4	20.3	18.3	21.8	19.4	16.1	152.0
8	17.7	21.0	17.9	16.4	16.8	15.4	13.4	118.6
9	10.2	10.1	11.1	10.8	15.1	17.1	15.8	90.1
10	15.7	15.9	17.5	17.5	18.0	19.6	19.2	123.3
11	28.0	23.1	22.0	27.8	25.4	20.8	22.0	169.0
12	48.0	47.0	45.3	47.2	43.8	51.0	49.3	331.7
13	11.0	11.0	11.0	11.0	13.0	14.0	16.8	87.8
14	1.1	1.1	1.1	1.1	1.1	2.1	2.1	9.9
15	14.0	15.1	15.0	18.0	19.0	21.3	21.2	123.5
16	11.0	13.2	13.5	14.0	16.5	21.2	23.3	112.6
17	5.8	9.0	9.0	9.0	9.0	11.2	11.2	64.2
18	10.3	11.6	13.9	15.7	14.7	12.7	11.8	90.6
19	36.2	34.8	40.7	47.6	48.3	45.8	46.8	300.1
20	362.3	353.0	353.1	671.9	659.9	613.9	559.7	3,573.8
21	2.0	2.0	4.2	5.3	6.2	7.8	8.0	35.3
22	8.8	11.5	8.5	10.3	10.1	11.8	11.8	72.7
23	17.3	13.1	14.7	15.1	15.4	16.3	17.3	109.3
Total	778.9	772.0	792.3	1,136.8	1,195.7	1,210.3	1,179.2	7,065.2

Table 2

Number of active research staff 1999–2005 (ftes, a)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	4.0	4.0	6.5	7.0	41.5	67.5	86.0	216.5
2	30.0	38.5	44.0	47.6	49.3	56.2	61.0	326.6
3	29.0	33.0	34.7	34.3	37.8	48.5	63.5	280.8
4	31.5	19.7	28.9	29.2	28.0	28.0	19.0	184.3
5	13.8	12.4	13.1	12.3	10.7	12.1	8.9	83.2
6	10.7	10.9	12.5	12.5	13.0	14.6	14.2	88.3
7	20.3	18.4	16.3	14.8	17.6	15.8	13.1	116.2
8	12.7	16.0	13.9	12.4	12.8	11.4	10.4	89.6
9	7.0	6.0	6.0	7.0	10.3	12.7	11.3	60.3
10	10.7	10.9	12.5	12.5	13.0	14.6	14.2	88.3
11	23.8	18.4	17.7	22.0	21.5	16.8	19.1	139.3
12	40.0	39.0	37.3	39.2	35.8	43.0	41.3	275.7
13	9.0	9.0	9.0	9.0	11.0	12.0	14.8	73.8
14	1.1	1.1	1.1	1.1	1.1	2.1	2.1	9.9
15	12.7	13.8	13.7	16.7	17.7	19.9	19.8	114.2
16	10.0	11.2	11.5	12.0	14.5	19.2	21.3	99.6
17	4.3	6.0	6.0	6.0	6.0	7.7	7.2	43.2
18	9.3	10.6	12.9	14.7	13.7	11.3	10.5	82.9
19	31.3	29.9	34.2	39.3	42.0	40.1	41.0	257.7
20	217.1	215.5	209.5	385.4	369.8	360.4	365.5	2,123.3
21	2.0	2.0	4.2	5.3	6.2	7.8	8.0	35.3
22	7.8	10.5	7.5	9.3	9.1	10.8	10.8	65.7
23	15.3	11.1	12.7	13.5	13.9	14.6	15.8	96.9
Total	**553.1**	**548.0**	**565.5**	**763.0**	**796.1**	**846.8**	**878.8**	**4,951.2**

Table 3

Number of senior research staff 1999–2005 (ftes, a)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	4.0	4.0	6.5	7.0	15.0	31.0	31.5	99.0
2	8.0	8.0	8.0	9.0	10.0	12.0	14.0	69.0
3	3.0	4.0	4.0	4.0	4.5	5.5	5.5	30.5
4	2.0	2.0	2.0	4.0	4.0	4.0	4.0	22.0
5	3.0	3.0	3.0	3.7	2.8	3.0	2.4	20.9
6	3.0	3.0	3.0	3.0	3.0	4.0	5.0	24.0
7	3.8	4.7	4.2	5.2	6.2	6.4	6.5	36.9
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	7.0
9	1.0	1.0	1.0	1.0	1.0	1.3	2.0	8.3
10	3.0	3.0	3.0	3.0	3.0	4.0	5.0	24.0
11	4.0	4.0	3.7	3.0	3.0	3.0	3.0	23.7
12	6.0	7.0	7.0	7.0	7.0	7.0	7.0	48.0
13	3.0	3.0	3.0	3.0	3.0	5.0	5.0	25.0
14	0.0	0.0	0.0	0.0	1.0	1.0	1.0	3.3
15	2.7	2.7	2.7	2.7	2.7	2.7	2.7	18.7
16	4.0	4.2	4.5	4.5	4.5	5.5	5.5	32.7
17	2.0	2.0	2.0	2.0	2.0	2.5	2.5	15.0
18	2.6	2.6	2.6	2.6	2.6	2.6	2.5	18.0
19	7.2	7.2	7.5	7.2	7.8	7.8	11.0	55.7
20	106.7	105.0	104.0	208.0	201.0	194.0	188.0	1,106.7
21	1.5	1.5	2.7	2.9	3.5	3.5	4.4	20.0
22	2.5	4.2	3.3	3.0	3.0	3.0	3.0	22.0
23	3.0	3.0	3.0	5.0	5.0	5.3	4.2	28.5
Total	177.0	180.0	181.6	291.7	296.6	315.2	316.7	1,758.8

Table 4

	Active research-ers on average	Refereed journal articles	Refereed confer-ence articles	Patents	Budgetary funds	External funding	Funding from inter-national sources (EU + Other)
	FTE	#	#	#	k€	k€	k€
1	30.9	77	47	4	450	4,008	1,043
2	46.7	35	82	3	9,450	9,440	1,873
3	40.1	50	212	44	11,143	9,051	347
4	26.3	15	121	0	3,638	3,907	145
5	11.9	12	19	4	2,800	1,883	41
6	12.6	31	55	1	3,679	3,449	1,204
7	16.6	50	59	2	2,379	7,260	802
8	12.8	15	5	0	2,883	7,009	381
9	8.6	50	43	2	911	2,287	740
10	12.6	31	55	0	450	1,208	0
11	19.9	38	133	0	3,307	3,233	292
12	39.4	17	103	4	7,351	8,320	96
13	10.5	103	0	1	2,312	1,659	0
14	1.4	3	7	2	0	450	0
15	16.3	104	26	1	8,579	2,070	436
16	14.2	9	100	7	3,109	6,160	0
17	6.2	4	17	0	1,110	900	0
18	11.8	34	97	0	2,501	2,977	259
19	36.8	230	53	22	2,430	12,030	1,510
20	303.3	426	380	75	60,652	199,794	24,258
21	5.0	58	28	0	0	3,165	700
22	9.4	8	16	0	0	590	130
23	13.8	202	231	2	1,653	2,618	1,491
Total	707	1,602	1,889	174	130,786	293,468	35,748

Appendix E2: Summary of funding resources

Tables 1–3

Table 1

Development of total research funding 1999–2005 (k€)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	21	233	156	273	1,127	1,861	809	4,480
2	0	0	3,263	3,502	3,570	3,949	4,606	18,890
3	2,022	2,084	2,669	2,288	2,784	3,846	4,501	20,194
4	1,022	1,109	1,268	1,197	1,101	903	945	7,545
5	638	622	670	707	714	772	561	4,683
6	859	904	1,087	1,042	1,032	1,120	1,084	7,128
7	1,756	1,782	1,314	1,192	1,298	1,205	1,092	9,639
8	1,214	1,445	1,726	1,496	1,359	1,620	1,142	10,002
9	360	375	440	540	520	460	585	3,280
10	0	0	0	0	0	0	1,658	1,658
11	1,096	1,012	987	1,033	861	699	852	6,540
12	1,948	2,458	2,479	1,873	1,862	2,498	2,553	15,671
13	537	586	433	551	486	692	686	3,971
14	0	0	0	0	0	0	450	450
15	1,380	1,509	1,651	1,710	1,583	1,502	1,314	10,649
16	823	896	1,253	1,219	1,658	1,736	1,811	9,396
17	350	410	430	410	380	400	390	2,770
18	520	658	789	905	992	872	742	5,478
19	1,580	1,850	1,970	2,400	2,320	2,440	2,560	15,120
20	27,897	29,801	28,969	51,781	47,503	47,079	49,850	282,880
21	360	160	440	430	590	500	685	3,165
22	0	0	0	0	0	0	590	590
23	529	551	553	648	578	699	713	4,271
Total	44,912	48,445	52,547	75,197	72,317	74,853	80,178	448,449

Table 2

Development of core research funding 1999–2005 (k€)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	21	31	44	46	100	103	127	472
2	0	0	1,800	1,800	1,800	1,900	2,150	9,450
3	1,098	790	1,675	1,305	1,434	2,428	2,413	11,143
4	519	623	525	534	500	398	539	3,638
5	429	389	375	378	403	402	424	2,800
6	451	455	512	527	563	592	579	3,679
7	372	326	265	353	365	343	355	2,379
8	431	458	387	406	402	490	419	2,993
9	125	125	135	128	135	145	145	938
10	0	0	0	0	0	0	450	450
11	484	497	506	522	477	433	388	3,307
12	1,117	1,165	1,084	928	933	1,112	1,012	7,351
13	265	276	262	309	284	456	460	2,312
14	0	0	0	0	0	0	0	0
15	1,034	1,231	1,294	1,396	1,281	1,243	1,100	8,579
16	335	322	338	533	537	576	595	3,236
17	190	230	270	290	290	300	300	1,870
18	331	320	312	351	484	399	304	2,501
19	260	380	310	360	480	640	660	3,090
20	7,393	7,032	7,993	15,260	13,553	15,024	16,831	83,086
21	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0
23	228	169	229	242	213	283	289	1,653
Total	15,082	14,820	18,315	25,668	24,234	27,267	29,540	154,926

Table 3

Development of external research funding 1999–2005 (k€)								
	1999	2000	2001	2002	2003	2004	2005	Total
1	0	202	112	227	1,027	1,758	682	4,008
2	0	0	1,463	1,702	1,770	2,049	2,456	9,440
3	924	1,294	994	983	1,350	1,418	2,088	9,051
4	503	486	743	663	601	505	406	3,907
5	210	233	295	329	311	370	136	1,883
6	408	449	575	515	469	528	505	3,449
7	1,384	1,456	1,049	839	933	862	737	7,260
8	783	986	1,340	1,091	957	1,130	723	7,009
9	225	240	300	407	375	305	435	2,287
10	0	0	0	0	0	0	1,208	1,208
11	612	515	481	511	384	266	464	3,233
12	831	1,293	1,395	945	929	1,386	1,541	8,320
13	272	310	171	242	202	236	226	1,659
14	0	0	0	0	0	0	450	450
15	346	278	357	314	302	259	214	2,070
16	488	574	915	686	1,121	1,160	1,216	6,160
17	160	180	160	120	90	100	90	900
18	189	338	477	554	508	473	438	2,977
19	1,320	1,470	1,660	2,040	1,840	1,800	1,900	12,030
20	20,504	22,769	20,976	36,521	33,950	32,055	33,019	199,794
21	360	160	440	430	590	500	685	3,165
22	0	0	0	0	0	0	590	590
23	301	382	324	406	365	416	424	2,618
Total	29,820	33,615	34,227	49,524	48,073	47,576	50,633	293,468

Appendix F: Panellists' reviews of the assessed units: Reports on the individual energy research units

Unit 1: University of Jyväskylä (UJ)
Department of Chemistry (plus others)
Renewable Energy Programme

Overview and mission
The Education and Research Programme in Renewable Energy (RE Programme) is focused on the development, promotion and research of sustainable energy systems. Launched in early 2003, it brings together teachers and researchers from three major divisions of the University: the Faculty of Mathematics and Science; the School of Business and Economics; and the Faculty of Social Sciences. In effect, it operates as a 'virtual centre', and is led by the Department of Chemistry. As such it is a bold and innovative attempt to create an interdisciplinary, cross-university capability. It offers a Master's programme in renewable energy. PhD training is undertaken within the individual university departments but the RE Programme provides a core focus for this activity. Current research themes include: biogas; biomass production; solar and wind energy; integrated RE-hydrogen systems and fuel cell applications; energy-related materials research; slow combustion in random media; and energy and environmental economics, policy and management studies.

Scientific quality, impact and viability
Given its recent origin, much of the academic output identified over the evaluation period (1999–2005) pre-dates the creation of the RE Programme, having its origins in the senior staff based at their core departments of the University. With this definitional proviso in mind, the level and range of academic output is high, including 77 articles in refereed international journals (some with high impact factors), 47 articles in international edited volumes and conference proceedings, 24 scientific monographs, four patents and a significant effort in the more popular media, including radio and TV. Some 60 students participate in the three MSc programmes (technology, the environment and socio-economics). The output of PhD students, supervised by the core academic departments rather than the RE Programme per se, is rising steadily, though from rather a low base.

Research environment and organisation
The general University facilities are modern and of high quality. It is recognised that it will take much longer than the three years since 2003 to build up high-quality experimental research facilities and measurement methods. EU funding via regional authorities has been frustrated by several bureaucratic problems, which it is hoped can soon be resolved satisfactorily. Given its recent history, and its cross-university character, the RE Programme is not yet a permanent entity but remains a 'virtual

centre' (see Recommendations below). The staff include five Professors, though with only partial FTEs (full-time equivalents) on RE Programme research, two research directors, three postdoctoral researchers and several PhD students. Given the breadth of the research agenda, and especially the departmental commitments of most senior staff, the distinctive research efforts via the Programme itself are as yet sub-critical – particularly compared with larger (and also interdisciplinary) research capabilities existing elsewhere in the EU and globally. An extensive national and international network of scientific collaboration is being developed, which should be reinforced as opportunities allow.

Interaction between research and society
A major contribution derives from the Programme's focus on interdisciplinary training of Master's students. In the longer term this should produce a significant cadre of well-informed students. The Programme has also developed extensive cooperation with business companies, research institutes and regional municipalities particularly on RE demonstration sites in Central Finland to promote public understanding of, and education in, RE technologies. The unit benefits from the close involvement of Professor Aho in VTT. The Panel also welcomed the Programme's efforts in the popular media.

Recommendations
The University is to be commended for encouraging the creation of the RE Programme in 2003. However, given the ending of the initial EU regional development support in late 2006, the University should – as soon as possible – provide a more permanent character to the Programme in a suitable manner. In conjunction with regional authorities, the EU, the Academy of Finland and appropriate ministries, the University should also seek to secure adequate funding for the Programme's longer-term equipment and staffing requirements. In turn, the Programme should now seek to map out, in some greater detail, its own future strategy beyond the 2006–2008 timeframe by undertaking frank and rigorous benchmarking and SWOT analyses. This strategic activity will be essential to secure firmer longer-term foundations for the Programme, perhaps more loosely-coupled to its 'host' departments; to guarantee its ability to develop its own, distinctive (interdisciplinary) PhD students; to strengthen links with other universities and research programmes; to inform its dialogue with the University, the Academy, Tekes and relevant ministries; to shape its plans to participate in wider research activities, such as the EU's 7th Framework Programme; and to inform future evaluations of the Programme's maturing research activity.

Unit 2: Lappeenranta University of Technology (LUT)

Department of Energy and Environmental Technology

Overview and mission
Three main research themes are being developed: (i) engineering thermodynamics focusing on multiphase flow, for which the unit has been awarded Centre of Excellence status for the period 2006–2007; (ii) nuclear engineering, specialising in safety research and education; and (iii) environmental technology in which the

emphasis is on waste utilisation, life cycle analysis (LCA) and environmental management from the corporate/producer perspective, as well as emissions trading.

Scientific quality, impact and viability

Scientific research output to date has been comparatively low (about 0.6 refereed publications per professor/year), though it was claimed these publications have high impact factors. The work on multi-phase flow is considered important and of high scientific value, as shown by its Centre of Excellence status. The unit claims that their problem-solving approach is a major strength. A modest number of patents (3) have been produced over the 7-year evaluation period. The unit is heavily engaged in short-term contract research, but they are seeking to enhance their basic research activities. They work closely with VTT in the bio-power and bio-heat fields. Perhaps reflecting the strong focus on applied contract research, the overall output of PhDs is about 0.25 per professor/year though; adjusting for the more research-active professors, this rises to 0.75 per professor/year.

Research environment and organisation

The unit has experienced significant growth over the evaluation period (1999–2005) in both funding and in research and support personnel. Funding increased sharply in the last two years. The professorial team has expanded from seven to twelve. Whilst, given time constraints, the site visit team did not visit the unit's research facilities, the overall building infrastructure appeared excellent.

Interaction between research and society

The unit has developed useful research collaborations with VTT (in bio-energy and nuclear engineering) and works closely with TKK in the field of computational fluid dynamics (CFD). International cooperation is quite extensive, including active participation in the International Energy Agency's Bio-energy Task 40, and the unit has well-established linkages with several research institutions in Russia. The unit has extensive interactions with the boiler industry and in fields such as biomass production and preparation, which has potentially important environmental impacts. The unit's work in nuclear safety was considered important in underpinning the recently announced expansion of the Finnish nuclear energy programme.

Recommendations

The unit should seek ways of increasing its focus on basic research, whilst maintaining its more applied activities. The newly appointed director of the unit is fully aware of this necessity. Critical to this rebalancing is the need to undertake frank and rigorous benchmarking of the unit's comparative strengths and weaknesses, at the Finnish and EU levels. Whilst important, the work on nuclear safety is on a comparatively small scale. This could be addressed by further staff appointments and/or by more effective networking in this field. The university is encouraged to commit the requisite funds for continuation of the current limited term professorship in the bio-energy field. Such an appointment could be used to stimulate the reconfiguration of the unit's efforts in the bio-energy field to ensure greater focus on leading-edge issues.

Unit 3: Lappeenranta University of Technology (LUT)

Laboratory of Electrical Power Systems

Overview and mission

The laboratory's activities in energy are mainly in the following areas: power systems and electricity markets; electric machines; and power electronics. In total the unit has about 63 researchers, of whom 5.5 FTE are professors, 15 are postdoctoral researchers and 30 are PhD students. This constitutes a little more than 60 %of the department's resources. The unit is the coordinator of the Finnish Graduate School in Electrical Engineering.

Scientific quality, impact and viability

The research model is centred on a dual structure consisting of basic research and industrial R&D. The latter occupies a very large space and results in extensive industrial contacts and an extraordinarily high output of patents (44 in 7 years), most of them owned by industry. The unit also has a high output of publications, both in refereed journals and in conference proceedings. 21 PhD examinations have taken place during the evaluation period 1999–2005. A number of spin-off companies have been founded, based on results from the unit. The industrial contacts are with both small and larger companies.

Research environment and organisation

The unit has a well-functioning structure that is regarded as appropriate. The strategy is well developed and the SWOT analysis and benchmarking efforts are very thorough. It is obviously one of the stronger units in Finland in the field of electrical power engineering, and compares well to similar units elsewhere in Europe.

Interaction between research and society

Most of the interaction takes place in research projects with industry. This interaction has been very successful, resulting in spin-off companies and many useful patents. Also, many of the MSc theses are undertaken in cooperation with industrial companies. A threat to the activities of the unit is the declining number of incoming students.

Recommendations

The unit should strive to establish international collaborations, EU projects and similar. It is deemed that the unit has even the capability of being the leading house in specific areas. The long-term recruitment of students seems to be a serious threat. To solve this problem, the unit should therefore establish a long-term strategy involving different activities.

Unit 4: University of Oulu (UO)

Department of Process and Environmental Engineering

Overview and Mission

The Systems Engineering Laboratory is one of eight laboratories at the Department of Process and Environmental Engineering. Its Power Plant Automation Group

(PPAG) represents about 40% of the laboratory's capacities and concentrates its research on power plant-related topics such as plant modelling, control and measurement techniques. PPAG's mission is to develop and apply advanced methods of modelling and controlling industrial processes to improve operation, productivity and the quality of products.

Scientific quality, impact and viability
Modelling, control and measurement methods are up to date and applied effectively. PPAG's staff is strongly represented at conferences. However, a continuing effort in publishing results is necessary to increase the impact of the scientific achievements. Given the relevance of the research topic for industry, support of MSc and PhD theses could be higher. Only 1 PhD was completed during the 7-year period 1999–2005. Increased interaction with comparable units outside Finland would improve the basis for the self-assessment. The contribution of the unit to the Department's award of Centre of Excellence status is recognised. A course programme in the area of specialisation has been established successfully, offering a course for the national Graduate School in Energy Technology. Important contributions have been made to the national FLAME programmes, the European COSY programme and Infotech Oulu. The narrow scope (concentration on and application to power plants) allows for an in-depth treatment of the main research topics, but constitutes a risk when the major problems of combustion control of solid (biomass) fuel combustion have been solved.

Research environment and organisation
With 9 researchers, of whom are permanently employed, PPAG has a capacity in power plant automation that is larger than that of similar university units elsewhere. Some work in the neighbouring 7 laboratories of the Department is related to energy, and it is intended that co-operation with them be enhanced. The other Engineering Departments have few energy-related activities. The use of locally available facilities (power plants and simulator) provides opportunities for practical application of research results. In many cases this has led to an improvement in plant performance.

Interaction between research and society
The concentration on solid fuel power plant optimisation is in line with the importance of biofuel utilisation in Finland. Both the education and the R&D components of PPAG contribute to the needs of Finnish industry and the energy sector in terms of well-trained engineers in the area of power plant operation.

Recommendations
Better cooperation with the other 7 laboratories of the Department will stimulate synergies and is part of the unit's future strategy. To increase the impact of the unit's output, a higher number of completed MSc and PhD degrees is needed. The opportunities for R&D cooperation and funding offered by the EU Framework Programme should be utilised, which would lead to improved interaction with similar units abroad. A future-oriented strategy should be developed, both for a diversification of the research area and to assist succession of the current head of laboratory.

Unit 5: Helsinki University of Technology (TKK)
Department of Mechanical Engineering

Laboratory of Energy Economics and Power Plant Engineering

Overview and mission

The unit consists of two distinct teams working in the areas of energy efficiency and process optimisation as well as energy economics. The first team is concerned mainly with development of biomass fuel drying technologies, energy efficiency in the paper industry, possibilities of reducing CO_2 emissions in the forest industry and exploitation of process integration methods. The second team works in the areas of large-scale energy system models, the effect of climate change policy on energy economics (mostly emissions trading), and risk management in the energy industry following market liberalisation. The unit has at present two professors and ten doctoral students, some of whom work in industry or at VTT. There are no post-docs and no other permanent academic staff; and an academic position at the intermediate, mid-career level has been open for several years.

Scientific quality, impact and viability

There appears to be little synergy between the two teams and the unit gives the impression of being rather heterogeneous. Despite the existence of a coordinating body for energy research at TKK (see section 3.3 earlier), the Panel did not see much evidence of cooperation with other units (see Chapter 3.3.1). Despite being in existence for seven years, the energy economics team does not have a strong research output, at least as indicated by its publication record. This may be due to the extensive teaching requirements associated with setting up entirely new courses. It seems to take a particularly long time to complete a PhD. The output of PhDs per professor is not high: 4 PhDs in seven years are too few. Both teams have real difficulties in expressing a clear vision for the future of their research programmes, as well as in benchmarking their achievements against those of comparable teams in other countries.

Research environment and organisation

Both teams do not appear to be networked strongly at the international level. A notable exception here is the participation of the energy economics team in the IEA Energy Technology System Analysis Project (ETSAP) and the International Institute for Applied System Analysis (IIASA). The process engineering team has had moderate success in attracting external funding and maintains strong connections with the relevant sections of Finnish industry. There are several joint projects with industrial companies, as well as some Tekes contracts.

Interaction between research and society

The work of the energy economics team is closely linked to the needs of society, as is the programme of the process engineering team by promoting the more efficient use of energy in industry.

Recommendations
There is an urgent need for stronger coordination and integration of the energy research teams working at TKK, as noted elsewhere. This unit has the most to gain from such coordination. Both teams are sub-critical in size: an extra member of the academic staff per team at the intermediate, mid-career level would be a decisive factor – both in increasing the research output and raising its quality. The Panel recommends the establishment of an advisory board by the Rector of TKK. This could provide advice and guidance for the research work of the unit in the next few years, and help build an international reputation, which it is clearly capable of achieving.

Unit 6: Helsinki University of Technology (TKK)
Laboratory of Energy Engineering and Environmental Protection

Overview and mission
The unit (ENY) is conducting research in support of Finnish industries in the areas of biomass utilisation, fluidised bed boilers, the pulp and paper industry, process integration, and $CO2$ capture and sequestration. ENY has 1 professor, 5 senior researchers, and 7 doctoral students; several atmospheric and pressurised fluidised beds; facilities and instrumentation for spray characterisation; and a unique endoscope capable of making measurements in the hostile environment of a black liquor recovery boiler. ENY has also been active in modelling single particle gasification and combustion, developing models for use in CFD codes; as well as models of heat exchanger networks and chemical processes.

Scientific quality, impact and viability
ENY's publication and thesis productivity compares well, when scaled with the number of professors or total researchers, with the Process Chemistry Centre at Åbo Akademi University (ÅA), a designated Centre of Excellence, as well as with comparable efforts at Chalmers University, Sweden. The ENY professor and one of the senior investigators (Dr Zevenhoven) have a commendable international reputation as measured by papers presented at international conferences, service on external evaluation committees for theses and energy programmes as well as awards. ENY has had personnel exchanges with major research centres in Europe and has been an active participant in Nordic energy research (NEF). The appointment of Dr Zevenhoven as a professor at ÅA is a credit to ENY. This move, however, creates both a problem in the loss of a valuable researcher and opportunities for strengthening collaboration with ÅA.

Research environment and organisation
A good balance has been achieved between industrial and academic research by maintaining a strong publication record while establishing good partnerships with industry. Researchers are motivated to produce high-quality publications by the posting of the best paper of the month, and by the annual recognition of the best paper, Master and PhD thesis, and textbook written by an ENY member. Conscious efforts to improve the educational quality and student environment were evident and successful.

Interaction between research and society
ENY's output of graduates and research supports the needs of the national forest products and fluidised bed industries, both important to the Finnish economy. In addition, ENY has provided annual courses in its core areas for 30 to 70 participants, with a strong international presence mainly from the Nordic and Baltic countries. The research on CO_2 capture by magnesium and calcium silicate minerals, such as serpentine and olivine, promises to provide an attractive alternative to CO_2 sequestration in saline aquifers. This is an option particularly well suited to Finland given its widespread deposits of magnesium silicates.

Recommendations
ENY recognises that it may be sub-critical to cover such a breadth of research activities in sufficient depth. It should pursue opportunities for consolidation of efforts with different units addressing similar problems in Finland. It is also recommended that the environmental consequences of the large-scale utilisation of minerals for CO2 capture should be examined in parallel with the development of the market potential for this technology.

Unit 7: Helsinki University of Technology (TKK)
Laboratory of Applied Thermodynamics

Overview and mission
The unit's mission, concluded from its name, is to provide education and scientific research in the field of applied thermodynamics broadly defined. In practice, research in one half of the unit is concerned with irreversibility of energy conversion in biological systems, fuel cells and other systems. Research in the unit's other half is focused on development and application of CFD (computational fluid dynamics), solution methods and turbulence models in single-phase flow. The CFD research is integrated with the activity of Finland's national CFD Graduate School at TKK and it has also effectively utilised national computing resources (CSC, Finnish IT Center for Science). The unit (2 professors, 3 postdoctoral senior researchers and 10–12 junior researchers and PhD students) is not large, but it is well positioned to grow and to take on substantial research challenges.

Scientific quality, impact and viability
The unit's research has a strong energy component. The topics have a pronounced basic research flavour, both in theory and method development, although one previous project on fuel cells has resulted in a licensing agreement with industry. The publication record (~7 refereed journal papers per year) is considered fair for a team of this size. However, the PhD completion rate is inadequately low (only 4 PhDs over 7 years for two active professors). Theoretical studies carried out in the laboratory on biological energy conversion have resulted in international publications and have led to a collaborative network (an EU COST project) on biological fuel cell research. Innovations in alkaline fuel cells, resulting from the unit's research, have led to the creation of a spin-off company. The CFD research has also resulted in a product (the FINFLO Code) for commercialisation. For the period under review (1999–2005) the unit had good extramural funding although, recently, the level of such funding has declined.

Research environment and organisation
The environment appears friendly, well-motivated and driven by the aim of scientific excellence. The team's innovative and entrepreneurial spirit is commendable. However, the unit's core organisation appears somewhat heterogeneous, with no apparent research collaboration between the two professors. Despite the unit's efforts at benchmarking and SWOT analysis, no significant or exciting research strategy is as yet being developed from this work.

Interactions between research and society
The unit's research on fuel cells, including biological fuel cells, is crucial to developing new avenues to environmentally-friendly energy conversion. Work on CFD is related to improving energy efficiency in industrial systems.

Recommendations
The Panel feels that the unit's activity in the CFD area would benefit from a more determined re-orientation into new domains of development and application, including multiphase-flow CFD. The research programme in energy conversion (thermodynamics) is creative; but a much clearer vision for industrial applications needs to be articulated for the programme to remain attractive for external funding. A particular priority is the need to provide a refreshed, updated basis for PhD training in this unit. The unit would also benefit from efforts to stimulate synergy between the two teams in tackling complex problems in energy research. Much greater interactions with other units at TKK are also strongly encouraged by the Panel. This unit, with strengths in basic energy sciences (thermodynamics, fluid dynamics, turbulence) has much to offer, and to gain, from such collaboration.

Unit 8: Helsinki University of Technology (TKK)
Internal Combustion Engine Laboratory

Overview and Mission
The Internal Combustion Engine Laboratory (ICEL) is part of the Department of Mechanical Engineering, which consists of twelve laboratories, six of which have a strong focus on energy-related topics. ICEL re-orientated its research strategy in 2002 when the current research areas were defined as 'engine-related fluid dynamics' and 'optical methods of engine combustion analysis' aiming at 'emission-free combustion' with an emphasis on renewable and alternative fuels.

Scientific quality, impact and viability
Fluid mechanics modelling capacity has been established using zero/one- and 3-dimensional CFD codes, like StarCD and KIVA. Recently, laser-based measurement equipment has been installed. These capacities represent state-of-the-art methods; however, the results of their application have so far been limited. The methods will probably have to be further developed to become distinctive and leading-edge, given what is already available elsewhere. The unit consists of a professor and a number of MSc researchers. The unit has industrial partners, like Wärtsilä, SISU Diesel and ABB, to apply its capacities to the solution of practical problems related to optimisation of internal combustion engines. The unit should be encouraged in these efforts. In turn,

this should lead to an increase in PhD numbers, which is seen as essential by the Panel.

Research environment and organisation

The energy-related work within the wider Department provides a good environment for ICEL's work. However, as experienced during the Panel's visits to the other laboratories at TKK, the considerable potential to exploit synergies has not, so far, been explored sufficiently. This applies also to ICEL, as regards their development and use of CFD codes. There is a strong need to establish a team of senior and mid-career researchers to realise the planned growth, both in terms of research volume and industrial cooperation. Thorough benchmarking of comparable research units abroad should provide a good basis for the future orientation of ICEL.

Interaction between research and society

In view of the importance of the transportation sector for both energy security and environmental impacts the improvement of internal combustion engine technology has high societal relevance. Therefore the work of ICEL has great potential to contribute to the interaction between research and society – in particular, if the planned enhancement of its contribution to graduate education and research is achieved.

Recommendations

ICEL should seek to mobilise synergies between the various laboratories of the Mechanical Engineering Department. The existing benchmarking overview of the international scene in internal combustion engine research should be used as the basis for the development of the unit's expansion strategy. In particular, the number of PhD students should be increased.

Unit 9: Helsinki University of Technology (TKK)
Department of Engineering Physics and Mathematics
Advanced Energy Systems – Solar Energy and Energy Storage (New Energy Technologies)

Overview and mission

The Energy Physics unit is one of two units in the Advanced Energy Systems section of the Department of Engineering Physics and Mathematics and one of the eight units at TKK covered by this evaluation. One main topic of research is solar energy where activities concentrate on ageing and degradation mechanisms in photoactive layers (both for photovoltaic and solar thermal applications), as well as on nano-structured dye-sensitised TiO_2 electrochemical solar cells that can be prepared on flexible, plastic substrates. The other main area of activity is fuel cells where the unit has specialised in the free-breathing polymer electrolyte type (PEM) and investigated transport processes and current density optimisation, in part by mathematical modelling. Some energy system studies have also been undertaken.

Scientific quality, impact and viability

The work in both main areas is of a high standard and has attracted considerable outside financial support, not only from Tekes, but also from the EU and industry.

Professor Lund has an excellent international reputation. The work is competitive with international, large-scale R&D in the photovoltaic and fuel cell fields. The unit has a good publication record and seems to have produced some excellent PhDs in recent years. It would profit greatly, however, from more funding for postdoctoral research, as well as from at least one permanent senior scientist position. Although positions at the 'intermediate' career level are at present filled, these are not permanent posts.

Research environment and organisation
The unit is well established at the EU level, but should perhaps be more strongly networked in the national and university (TKK) context, especially with units that also have a high reputation. The unit works closely with industry in the area of photovoltaics, in particular on the ageing problem. The unit is rather small (in view of its high international reputation) and consists of 1 professor, 1 temporary senior researcher, 1 post-doc and 7 PhD students.

Interaction between research and society
The head of unit takes part in national debates on energy issues and provides information for parliamentary and governmental decision-making. He also provides technical and policy advice at the EU level.

Recommendations
In its vision for the future the unit expresses some interest in expanding its energy system studies. This must be considered very carefully and only embarked upon if the unit can offer something really exciting and distinctive. There are already several teams undertaking research in this area in Finland.

Unit 10: Helsinki University of Technology (TKK)
High Voltage and Power Systems Laboratory

Overview and mission
The main research areas are in power transmission and distribution (T&D) systems and their information technology and comprise: (i) load capacity, diagnostics, ageing and condition management of power systems and their components; (ii) system technology, planning methods and the security and reliability of T&D systems; and (iii) ICT applications supporting these, including computer systems, data communication, automation, instrumentation and sensors. The team is developing a research strategy that is influenced by the evolving research agenda in these fields and well-suited to its resources, personnel and facilities.

Scientific quality, impact and viability
The unit's research output over the period 1999–2005 comprised 20 articles in international refereed journals, 66 articles in edited volumes and conference proceedings, 2 patents, 112 other scientific publications and 6 completed PhDs. There were no significant visits overseas and there were 3 visiting professors. The main scientific collaboration has been with Germany, Sweden and the UK. Though the professors have been involved in several international scientific committees, the team

has not made any presentations to scientific conferences, is not on any editorial boards, and has not received any scientific prizes. The team is undertaking a scientifically interesting portfolio of research, is enthusiastically led, and has expanded in recent years. The increased focus on publications in international refereed journals is welcome and must be implemented.

Research environment and organisation

The laboratory, led by Professor Lehtonen, comprises 2 professors, 24 researchers and postgraduate students, 4 technicians and 1 administrator. It has large and modern laboratory facilities for research and testing, which include the most extensive high-voltage laboratory in Finland. A very broad range of funding has been secured, more than 70+% of which comes from external sources including the Academy of Finland, Tekes, and especially industry. However, none of this funding comes from abroad.

Interaction between research and society

Research is carried out in close cooperation with power companies, manufacturing industry and relevant state authorities. No other evidence of interactions was provided by the laboratory.

Recommendations

The unit has recognised strengths, certainly at the national level. But it cannot afford to be (or to appear to be) complacent. Several sections of the unit's self-assessment report were disappointingly brief. The unit should now undertake rigorous benchmarking and SWOT analysis. This should be used (i) to identify a medium-term research strategy in leading-edge areas; (ii) to seek means of securing more funding and research time for 'blue sky' work; and (iii) as a way of exploring the unit's future role in EU and wider, international research activities. Greater emphasis should be placed on academic research output in refereed journals.

Unit 11: Helsinki University of Technology (TKK)

Laboratory of Electromechanics

Overview and mission

The unit's mission is to provide education and scientific research in the field of electromagnetic energy conversion. The focus in research has been placed on developing and applying methods of electromagnetic analyses to study rotating electrical machines, control and damping of rotor vibrations in such machines, fault diagnostics, efficiency and dynamics of electrified turbochargers, as well as other topics in electromechanics. Research topics have been formulated via interactions with industry or to address industrial needs. The unit has successfully collaborated with industry.

Scientific quality, impact and viability

The unit's accomplishment during the review period (1999–2005) is very well benchmarked against similar units in their fields internationally, both in terms of industrial funding, refereed journal publications (3.8 per annum) and PhD theses (10.5 PhDs during the 7-year period). The unit's professors have developed a broad international network and are well recognised in the international community for their scientific research and developments. Most importantly, while developing a strong base with industrial projects, the unit maintains a strong emphasis on scientific publications in international refereed journals.

Research environment and organisation

The unit is of a good size (1 professor, 3 senior researchers with advanced degrees, ~10 PhD students and junior researchers). PhD students in the unit are young, including female and international students. The unit has the appropriate infrastructure and atmosphere to facilitate quality research and training of graduate students. This includes a modern laboratory, suitable availability of equipment, technician assistance and supervisory capability (including the unit's professor, professor emeritus and several senior researchers).

Interactions between research and society

The unit's research addresses important issues in electrical machines that are of relevance to efficient energy conversion and usage. Graduated students have gone to work in industry and at the Academy of Finland. Software developed by the unit is used in industry and in other institutions in Finland.

Recommendations

The Panel commends the unit's academic performance and contribution to industry needs and sees potential value in the unit's plan to develop new capability in multi-physics modelling and simulation.

Unit 12: Tampere University of Technology (TUT)

Institute of Energy and Process Engineering

Overview and mission

The institute is essentially a traditional mechanical engineering unit operating in a wider, interdisciplinary, environmental engineering effort. The main research areas include: heat pumps and refrigeration technology; HVAC technology; fluid dynamics and heat transfer; combustion technology; and power plant technology. A total of about 30 active researchers are engaged at the institute, five of whom are full professors. The declared mission of the institute is to serve industry by undertaking long-term projects of technical and scientific relevance and significance.

Scientific quality, impact and viability

The focus of the institute lies on long-term industrial projects with the aim of solving practical, 'real world' problems. The work in this regard has been very successful. However, the number of papers published is fairly small for a unit of this size; this applies to both journal and conference papers. One reason for this is confidentiality issues. Whilst the institute has several scientific exchanges with international counterparts, national cooperation predominates. There is good external financial support, particularly directly from industry.

Research environment and organisation
The research is organised in three laboratories: power plant and combustion engineering; fluid dynamics and heat transfer; and a test laboratory. Most of the work is done within these individual laboratories, but some cooperation occurs between them. Researchers can move between these laboratories, depending on funding and personal interests.

Interaction between research and society
Most of the interaction takes place in the numerous projects with industry. Another important way is through the relatively high production of PhDs by the institute (12 during the 7-year period).

Recommendations
The high level of industrial funding is one indicator of success and scientific relevance. But universities are not simply confidential contract research organisations. Ways should be identified to improve the communication of results through refereed scientific and technical papers.

Unit 13: Tampere University of Technology (TUT)

Institute of Materials Chemistry

Overview and mission
The photochemistry team of this institute has focused on the photodynamic study of molecular systems. It has considerable accumulated research experience in studying complex molecular processes with spectroscopic methods. The two main research fields are photochemistry and supramolecular assemblies.

Scientific quality, impact and viability
The unit was judged to have excellent fundamental scientific knowledge and the ability to create nanosystems that work as electron transfer devices. Research specialties include spectroscopy, kinetics of rapid electron transfer photoreactions, and supramolecular assemblies. A major achievement is the conception and development of structures whose photovoltaic efficiency has reached 17%. Both research productivity and quality are high: over this 7-year evaluation period 103 articles have been published in refereed international journals, 9 PhDs awarded (virtually all now employed in academic posts), and 1 patent obtained.

Research environment and organisation
The unit is led by Professor Lemmetyinen, supported by 4 research associates, 2 post-docs, 8 doctoral students, a technician and an administrator. They are a closely-knit team, with an appropriate balance between research and teaching activity. Financial support from the university has increased significantly since 1999, and now represents two-thirds of total funding. Compared with other units evaluated by the Panel, the ratio of this unit's core (and basic) research funding is very high. The research facilities are considered adequate for the current research portfolio. The team has developed close linkages with both Kyoto and Osaka Universities in Japan.

Interaction between research and society
The unit forms part of the wider nanomaterials effort at the national level acting as coordinating group of a research project entitled Organic Solar Cell in Tekes' FinNano Programme. They consider themselves the leading unit in photochemistry in Finland. The research is seen as important by the Panel, with considerable potential for renewable energy and wider nanomaterials applications. Should the team succeed in developing structures that absorb light in a wide frequency band, and at an overall efficiency at or over 25%, they will have made a major scientific contribution.

Recommendations
The unit should ensure they continue their leadership in this field in Finland. Having been in existence for some 13 years, the unit should now undertake much more detailed benchmarking and SWOT analyses, and seek to interact more effectively with other related research at Finnish and other EU universities.

Unit 14: Tampere University of Technology (TUT)
Institute of Automation and Control

Overview and mission
The institute is led by Professor Koivisto and comprises some 50–60 researchers whose research focus is on systems engineering and control. The energy-related component (under Prof. Lautala) forms only a very small part (5%) of this larger institute. Over the period 1999–2005, energy-related research has had four main aspects: (i) optimisation of a chain (or series) of hydro-electric power (HEP) plants and planning HEP production; (ii) modelling, simulation, control and diagnosis of industrial power plants; (iii) control and diagnosis of small-scale wood chip and pellet-fired combustors; and (iv) means of improving industrial energy efficiency in the wood grinding process. The research on HEP plants is not currently active, and work now addresses the latter three topics. Much of the research has been undertaken as part of a small number (3) of PhD theses.

Scientific quality, impact and viability
Even allowing for the small size of the energy research team (see below), research productivity in this field over the 7-year evaluation period appears low: 3 articles in international refereed journals, 7 articles in edited volumes and conference proceedings, 2 patents and 3 completed PhDs. Only one of the best publications provided to illustrate the unit's energy-related research was by Professor Lautala. The unit's evaluation report provided no evidence of international cooperation via visits to or by the team. No conference papers, journal editorships or prizes were identified. The team has provided advisory and consultancy expertise for several industrial projects. Professor Lautala has served as Chair of the Advisory Committee on Nuclear Safety.

Research environment and organisation
Professor Lautala's commitment to energy research is identified as only 5% of an FTE over the period, complemented by 1 senior researcher and 1.1 FTE postgraduate students. The Panel could not identify any research strategy in the energy field, and

could not identify any moves by the unit to increase the volume of energy research. No meaningful analysis of the team's funding by the Panel was possible, given the very limited data provided. But the team has apparently received considerable financial support from Tekes, and a smaller amount from industry. It appeared that much of the research activity is shaped by ad hoc industrial applications.

Interaction between research and society

Other than the (limited) contributions to postgraduate teaching and some modest industrial collaboration, again no evidence was provided by the unit on this topic.

Recommendations

The Panel was concerned that so little of the self-assessment form had been completed by this unit, despite the fact that it requested quite routine academic and financial information. This gave a strong impression that the evaluation was seen as a distraction of marginal importance or relevance.

Given the Panel's concerns about the sub-critical ('orphan') character of the energy-related team at this institute, the Panel sought to explore the scope for collaboration (or possibly merger) with other research units – at TUT or elsewhere. We appreciate that the host Institute of Automation and Control has a large staff, but this specific energy-related component is very small indeed. We recommend that the university, the Academy of Finland and Tekes explore the scope for such collaboration or, more radically, the relocation of this energy-related activity.

Unit 15: Tampere University of Technology (TUT)

Institute of Electromagnetics

Overview and mission

The unit has three main research areas: basic research on the mathematical physics of electromagnetism; superconductivity; and electrical motors and generators. The main research agenda and mission are not primarily focused on energy applications, but a significant part of the activities in superconductivity and electrical machines, i.e. wind power, can be regarded as energy research. The statements and assessment in the following apply, if not explicitly stated, only to the energy-related research concerning superconductivity and electrical machines; the other areas of the institute's research were not subject to evaluation.

Scientific quality, impact and viability

The numbers in the following apply to the whole institute, since no numbers for the energy-specific research were available. Research productivity, as measured by publications, has been high: 104 refereed journal articles over the past 7 years. The unit produced just over 1 PhD per year. Of the 8 who graduated during the evaluation period (1999–2005), 3 are now working at the unit as post-docs. The unit's strengths include an impressive publication record; a fair number of graduates; and a reasonable level of international exchanges. Its weaknesses derive partly from a sub-critical level of activity in superconductivity and wind power.

Research environment and organisation
The unit is led by Professor Kettunen, supported by 2 senior staff, 1 docent, post-docs, 10 graduate students and 1.3 FTE administrators. Two of the senior staff members work with superconductivity and wind power, but no information was available on how many PhD students are active in these fields.

Interaction between research and society
Other than participation in the Magnet Technology Centre it appears there has been little interaction with other similar research teams in Finland or elsewhere in the EU when it comes to energy research. The main industrial contacts have also been through this Technology Centre and the level of industrially-funded applied research appears to be low. International cooperation has been robust, but in a rather continuing manner. The wider societal and environmental relevance of the team derives from the potential for higher energy efficiency gains leading to lower carbon emissions.

Recommendations
The Panel formed the view that the core research agenda concerning superconductivity and wind power has remained essentially unchanged over the past 5 years or more. To maintain a significant place in the overall national energy research programme, it is suggested that one priority is to examine afresh a new, coherent research strategy for the whole institute which should, inter alia, review interaction between the three major research areas. The energy research activities appear to be sub-critical, especially in wind power. The new strategic plan should be drafted through thorough benchmarking and SWOT analysis, with the aim of refocusing objectives and establishing new milestones. Opportunities are seen to exist via intensified engagement with the Magnet Technology Centre, permitting greater interactions both with industry and other universities.

Unit 16: Tampere University of Technology (TUT)
Institute of Power Engineering

Overview and mission
The institute is part of the electric engineering department and focuses on three main research fields: electrical energy; power systems and markets; and high-voltage engineering. Distributed generation (wind power) is included in the first of these activities. In 2005 the institute had just over 20 researchers, of whom 2.5 FTE are professors. The research team has essentially doubled in the past five years and has now reached a size that is regarded as appropriate.

Scientific quality, impact and viability
The research is of a high national standard and, in some areas, at a good international level. A diversified and high level of external funding provides a suitable basis for the work. During the expansion period over the last five years the unit has thoroughly formulated a strategic plan to achieve set goals and the team is well aware of its position in Finland. The unit's self-assessment reflects very well its strengths and weaknesses. The number of PhD completions in recent years has been fairly low, but

the current number of PhD students (12) will improve this in the future. Publications have mostly been via conference presentations, but greater efforts are now being made to increase the number of refereed journal publications, a step encouraged by the Rector. International contacts are predominantly with other Nordic countries.

Research environment and organisation

The research is organised in teams according to the research activities mentioned above. A special research asset is the high voltage laboratory, where work mainly related to distribution systems can be undertaken. In the climate chamber, different weather conditions (temperature variations, rain, snow etc.) can be simulated, and this particular research facility provides the team with a competitive advantage. The institute cooperates with other departments at TUT, for example with the physics department.

Interaction between research and society

Most of the interaction takes place in research projects with industry. The high voltage laboratory also offers research services for industry. One of the professors has a 50% employment at the university and 50% in industry (ABB), which facilitates university-industry interaction. Many of the MSc theses are undertaken in cooperation with industrial companies.

Recommendations

As part of its evolving research strategy, the unit should endeavour to establish wider research links with units elsewhere in the EU. The unit has a unique asset in its high voltage laboratory with the climate chamber. This asset should be used to position the institute as an attractive partner for international projects. It is recommended that more projects of deeper fundamental and scientific interest be started.

Unit 17: University of Vaasa (UV)

Department of Electrical Engineering and Automation

Overview and mission

The department has a short history of research in the energy field. Expertise in transient simulation obtained during 1996–2001 has formed the basis for two main research areas: integration of distributed generation, particularly protection issues; and new technical solutions for electric distribution networks. These activities have been developed in collaboration with local industrial partners. The unit is fairly small, 7 researchers, out of which 2.5 are professors and 2 PhD students. Plans are to expand the unit to critical size by 2010, i.e. comprising 4 professors, through of 2 new industry-funded professorships.

Scientific quality, impact and viability

The activities are in an initial phase and the output from the unit is still modest, but the quality is of a good national standard. Only a few papers have been published, mostly at conferences, and only two PhDs in the energy field have been awarded. A plan for further development exists, where the goal is to gradually expand the activities from a local to a European basis. The industrial partners, which are very active in supporting the unit and the formulation of the plan, have global activities.

Research environment and organisation
The unit has excellent and new laboratories. Even if they are primarily intended for undergraduate teaching, they can also be used for some research projects. The Ministry of Education has been instrumental in providing resources for the laboratories and other research equipment. A problem for the unit is the lack of a strong research tradition at the university in the engineering field. Most of the interaction must therefore be with other universities and with local industry.

Interaction between research and society
The unit has very good interaction with local industry and it receives good support from these industrial partners, though industrial funding has declined in recent years. The interaction with other Finnish universities takes place via the Graduate School for Electrical Engineering and in some Tekes-funded projects, e.g. Network Vision for 2030. The main focus of the unit is to educate skilled engineers (at MSc level) for industry.

Recommendations
The planned work in bio-oils should be conducted in close cooperation with ongoing national and international research being carried out elsewhere. The research on energy storage should be expanded beyond batteries. Greater emphasis should now be placed on academic publications in refereed journals.

Unit 18: Åbo Akademi University (ÅA)
Heat Engineering Laboratory

Overview and mission
The unit's mission is to provide basic chemical engineering education and scientific research in thermodynamics, heat and mass transfer as well as process engineering. The unit's work covers several topics related to energy research. These range from fluidised bed simulation, gas-liquid flow modelling and simulation to process optimisation; and from energy distribution and conversion, bioprocessing and waste treatment to CO_2 capture and storage. The research has strong analytical, synthetic and computational ingredients. The unit's activity is well supported by the university's core funding (45%) and external funding (including 26% from Tekes, 14% from industry and 5% from the EU). With 2 professors, 3 senior researchers (with PhD degrees), and 5–6 other researchers (with MSc or LSc degrees), the unit is well positioned to expand.

Scientific quality, impact and viability
Over the review period (1999–2005), 34 articles were published in international refereed journals and 7 PhD theses were completed. Among the 7 best publications submitted, 2 related to CO_2 capture and storage – a new, important topic brought to this unit with the appointment of Professor Zevenhoven. Other publications focused on blast furnace and heat exchanger networks and other topics closely related to

industrial needs. The unit's research productivity, scientific quality and impact are adequate for its size, funding and teaching responsibility. The Panel views this unit as viable, having now developed the critical mass and other elements needed to generate greater impact in the energy research field.

Research environment and organisation

The unit has recently been strengthened by the successful recruitment and appointment of Professor Zevenhoven. Both professors (Saxen and Zevenhoven) have strong motivation and a well-articulated vision for energy research, with a promise for their synergy. The unit is well integrated in European and international collaborative networks.

Interactions between research and society

Research in this unit has a strong energy and environmental context, built on the unit's close connection to industry. Members of the unit actively serve on boards and committees both in Finland and abroad.

Recommendations

The unit's professors have a commendable plan to further broaden the scope and extend new frontiers in energy and environmental research. Yet the Panel notes the unit's reluctance to benchmark itself against peer national and international units in the field. This benchmarking is encouraged by the Academy of Finland and by this Panel as an important element of self-assessment. Indeed, elsewhere in this report, the Panel recommends that the results of such benchmarking and SWOT analysis form part of all research grant applications. The Panel feels that the unit's research impact would benefit from deepening its commitment in basic engineering science, especially in those selected areas where the unit has already established relevant expertise and capability.

Unit 19: Åbo Akademi University (ÅA)

Process Chemistry Centre

Overview and mission

The Process Chemistry Centre (PCC) is an interdisciplinary unit focused on the detailed understanding of the physico-chemical properties of molecules in order to better design chemical processes – a research area designated Molecular Process Technology. In order to achieve these goals, the PCC has developed the necessary skills in chemical and thermal analysis, modelling, reactor technology, as well as chemical and physical characterisation of surfaces at the microscopic level. The PCC is larger than many other university research units, comprising 6 professors, 22 senior researchers and 39 doctoral students. Approximately 35–40% of the PCC's activities are devoted to energy, with a focus on the chemistry of biofuels, their properties and thermal conversion.

Scientific quality, impact and viability

The PCC has been extremely productive by every measure. During the evaluation period (1999–2005) the PCC has published 570 peer-reviewed papers (circa 230 in energy research) in premier chemical engineering and fuel journals, and graduated 47 doctoral students (20 in energy). Its faculty has served on editorial boards of journals and has leading positions on international committees. The PCC has twice been designated a Centre of Excellence, for the periods 2000–2005 and 2006–2011. Members of the faculty are recognised nationally and internationally, as evidenced by presentation of invited lectures at major relevant international society meetings as well as multiple awards including the prestigious Finnish Science Prize. The PCC has, in addition to conducting high-quality basic research, worked closed with industry on translating their research results into practice, filing over 40 patents (circa 20 in energy); they received about one-sixth of their funding from industry. The research with the highest potential of impacting on industry is that on the production of oxygen-free bio-diesel and the development of forest bio-refineries to produce multiple, high value-added products and energy from wood in addition to pulp and paper. The PCC is also continuing research relevant to existing technologies on black liquor combustion and evolving technologies on gasification.

Research environment and organisation
Professor Mikko Hupa has provided remarkable leadership for the PCC. He has a clear vision of the future directions for the programme; he has developed an efficient organisational structure; and he leads by example. Forest bio-refineries provide a commendable new emphasis for the PCC. The centre has built up first-rate facilities, in part using support received through the two Centre of Excellence periods.

Interaction between research and society
The research in the PCC addresses Finland's needs for power and chemicals from domestic renewable resources. This demonstration of the importance of process chemistry in converting Finland's abundant forest resources into a clean and sustainable energy source will contribute to changing the negative public image of chemical technology and make the subject more attractive to young people. The PCC is active in communicating their technical contribution to society through the print and electronic media.

Recommendations
The energy-related component of the PCC needs to develop a policy for the professional development of its graduates and younger scientists. The PCC, as the premier and largest combustion unit in Finland, has naturally hired its own graduates, since they represent the largest pool of talent in their field. Measures are needed to avoid the problems of inbreeding. A postdoctorate appointment is an appropriate stepping stone to industry or teaching but care should be taken that graduates do not stay beyond the point of diminishing returns, usually two to three years beyond obtaining their PhD (8 of 19 PhDs graduated since 1999 are employed at ÅA). Of greater concern is the development of future faculty, through retention of PCC graduates. Those being prepared for such positions should be sent to Centres of Excellence in their chosen fields outside Finland to develop new perspectives for a suggested period of two years, as discussed in the Evaluation Panel's general recommendations. Noting that only two out of 18 docents in the PCC are active in

energy-related fields, and one has since accepted a position elsewhere, there is concern about the future leadership of this strong team.

The PCC has developed new capabilities in computational chemistry. It is important to develop strong ties with leading units in combustion chemistry (Vovelle & Dagaut, CNRS, Orleans; Simie, NUI, Galway; Ranzi, Polytechnic, Milan; Westbrook, LLNL, Livermore; Green, MIT; Tsang, NIST; etc.) as has been done in other areas of combustion.

Unit 20: VTT – Technical Research Centre of Finland (VTT)

Most of VTT's energy research is carried out in the Knowledge Cluster Energy and Pulp &Paper (EPP), one of 7 VTT Knowledge Clusters. Its structure reflects the energy-related priorities of Finland: nuclear energy, renewable energy sources and energy use in the pulp and paper industry. The capacities needed are organised in 7 research areas with a total of 410 FTE research employees, of which around 385 are working in energy research. This is by far the largest capacity for energy research in Finland, comprising some 43% of the research effort evaluated in this Report. The broad, internationally recognised research activities on energy are based on a clearly formulated and implemented strategy with the multiple objectives of:

- carrying out innovative research to develop new ventures in partnership with industry;
- helping industry improve its global competitiveness;
- providing policy-makers with tools for decision-making on energy options;
- supporting the energy industry (nuclear and non-nuclear) in technology development, operational safety and economy; and
- working collaboratively with universities in both the educational and research arenas.

The unit report on EPP is divided into two parts: Non-nuclear work in Otaniemi and Jyväskylä; and nuclear work in Otaniemi.

VTT Energy and Pulp & Paper – non-nuclear work

Overview and mission

The mission is to perform energy research along the entire chain of technology development and application of renewable sources of energy, from basic research through product development to expert services and testing. The work is application-oriented to meet the needs of industrial partners in their technology development, and the public sector in its decision-making processes. The efforts cover a variety of topics along the energy chain: energy resources (biomass, wind power); energy conversion technologies (combustion and gasification for heat and power production, production of advanced liquid biofuels, material technologies for power engineering, fuel cells and hydrogen technology, engines and vehicles, and emission reduction); energy end-use optimisation (demand-side management and energy conversion systems optimisation in buildings and industry); and energy systems studies (market analysis, greenhouse gas issues, transport and storage).

Scientific quality, impact and viability

In the area of non-nuclear energy, good and solid work was conducted, from basic research to applied engineering that has resulted in an impressive list of achievements. The excellence of many of the investigators has been recognised internationally by invitations to present lectures, and service on editorial boards and review panels. Well-established areas (bioenergy systems and technologies, engines and vehicles, energy system modelling etc.) are being continued in a systematic manner. These have established an enviable international reputation (and led to significant funding), and form the basis for meaningful collaborations with national universities and major relevant international energy organisations. The heavy load of contract research and constraints on publishing proprietary material have resulted in a publication volume that is low, based on either the funding level or the number of senior researchers.

The scientific quality of the work is assured through both a highly motivated and well-trained staff, and state-of-the-art laboratory equipment. International cooperation plays an important role via participation in EU Framework Programmes and in IEA Research Networks. A strong market orientation, both in terms of the R&D market and the resulting market for the products developed, assures a positive impact for the unit's research results.

Research environment and organisation

Research work at VTT is predominantly based on contract research financed through external sources from industry and publicly-funded national and international programmes. One-third of the required funds is provided through base funding from governmental budgets. Recent closures of R&D capacities in energy-related industry (e.g. Foster Wheeler's entire R&D group) have had some positive effects on the unit both in terms of new personnel and research work. On the other hand, reorganisation and outsourcing have resulted in a slight decrease in staff in recent years. Despite the continuing support for VTT through the national funding agencies, increasing R&D capacities in universities and regional agencies represents a challenge for maintaining the funding level. Most of the funding from Finnish public programmes is via Tekes, which generally requires industrial co-funding. In 2005, a substantial budget was provided by Tekes for investment in new research equipment.

Unlike the other energy research organisations, education and training is not a primary goal for VTT. The concentration on R&D has led to the development of a highly professional operation, compared to some university-based R&D. However, R&D cooperation with universities is important for the unit's work and leads to synergies for the applied research at VTT and for the MSc and PhD programmes at partner universities. Yet, these synergies could even be further exploited if research strategies of the universities and VTT would be coordinated at an earlier stage of development.

Interaction between research and society

The importance of securing a sustainable future energy supply is widely recognised by Finnish society. EPP's work is fully devoted to this and has therefore a high acceptance by both public bodies and society at large. The application-oriented R&D work, combined with a certain fraction of underlying basic research, assures the transfer of results to industrial application. VTT has been outstanding in communicating the importance of energy to policy makers and the public. They have used in-house resources to publish Energy Visions 2030, a very readable report, amply supported by informative visuals, of the global problem of declining fossil resources and challenging environmental problems.

A certain conflict of interest may be observed in VTT's policy related work. On the one hand, VTT is called upon to apply its great competence to support the development of national policy and strategic planning; on the other hand, VTT is – naturally – interested in carrying out the R&D work resulting from its engagements in policy and strategic planning. This illustrates a key dilemma confronting public R&D funding: should the programmes be carried out in a long-term partnership with one (or a few) preferred partners to assure continuity and utilise the accumulated expertise; or should there be some degree of competition at the expense of continuity?

Recommendations

As recognised in the self-assessment, EPP would benefit from improving their networking with academia to provide greater collaboration and opportunities for staff renewal at EPP and for outsourcing specific tasks instead of competing for them. The opportunity for synergy between the universities and EPP has not been fully realised. Consideration should be given to what is the best mechanism to utilise universities for more basic research taking into account the time scales of master's and doctoral theses, as well as VTT's facilities, expertise and ability to translate results to industry.

The need to secure continuous funding, but also to work on cutting-edge topics, for which limited funding is available, are challenges that VTT has clearly recognised. International cooperation should continue to be a high priority. Staff development should continue to be a prime issue to assure optimum utilisation of more experienced staff, whilst also recruiting new blood, i.e. younger scientists to provide fresh insights into the issues being tackled.

VTT Energy and Pulp & Paper – nuclear work

Overview and mission

The utilisation of nuclear energy for electricity production is a major corner stone in Finnish energy policy. While the nuclear power plants are supplied by foreign vendors, the plant operators have put high priority on the safe and economic operation of the plants and on fuel cycle issues. Thus, EPP efforts at Otaniemi have priorities in nuclear power plant operational safety, nuclear waste management and energy system modelling. Research on material technologies, automation systems and reliability analyse for nuclear power engineering is carried out in other research clusters within VTT.

Scientific quality, impact and viability

Several teams at EPP are working on reactor technology and reactor safety. These (altogether about 60 researchers) are well integrated into European research and have excelled in the distillation and transfer of knowledge to the nuclear industry and the Government to meet Finland's needs. The heavy load of contract research on reactor safety and waste management as well as constraints on publishing proprietary material have resulted in a publication volume that is low, because of the low-level basic funding available for supporting basic research. Research results in reactor technology, safety and waste management by the research teams of EPP were presented in 45 refereed journal papers over the review period 1999–2005. Many of these publications reflect VTT's participation in EU projects and collaborations. In VTT the total headcount is about 200 researchers in nuclear energy. Nevertheless, the spread of human resources appears thin, and may be sub-critical to achieve the impact needed in the science and technology of nuclear fission.

It appears that the drive for basic research in fission energy has been de-emphasised, perhaps because industry needs are in the area of nuclear power plant operation. This trend must be reversed if Finland is to attract talent to the fission energy field as a whole and assure a sound foundation for future use of fission energy.

The effort in nuclear fusion is considerably smaller than that in fission (less than a tenth in terms of resources). The activities are integrated into the European fusion programme and organised within the framework of the Euratom-Tekes Association based at VTT. EPP plays a leading role in fusion technology, collaborating closely with industry and universities. It is also active in the highly visible fusion physics programme, working closely with TKK. The research results of the unit have been published in about 80 refereed journal papers over the review period 1999–2005.

Research environment and organization

The researchers are organised into a well-balanced structure of project managers, research managers, professional researchers as well as technical and administrative support staff. The analytical, bench- and pilot-scale facilities are first rate. Inducements for employees are stability of employment and opportunities for professional development, with time (half-a-day/week) made available for continuing education (25 employees have been granted PhDs during the period reviewed). The ageing profile of the researchers, particularly in the nuclear area, was recognised only lately; recent staff recruitment has resulted in a bimodal age distribution, a problem that needs to be monitored and corrected as needed.

There already exists a platform for interaction and collaboration between VTT, TKK and LUT in education and training in nuclear engineering. In fact, the Panel understands that a majority of the PhD theses by VTT researchers were examined at TKK and LUT. However, it appears that the link (particularly to TKK) is pro forma rather than substantial.

Interaction between research and society

The importance of nuclear energy in securing the future energy supply is widely recognised by Finnish society. EPP's nuclear work is fully devoted to this and has, therefore, a high acceptance by society

Recommendations

The Panel believes that nuclear power plant safety must be achieved through continuous and persistent efforts for excellence in R&D; and that VTT has the necessary ingredients to satisfy this need. It is recommended that VTT enhance its research in the reactor safety area, including continuation and strengthening of efforts to develop advanced methodology for accident analysis and accident management.

This is consistent with Finland building the first-of-a-kind Generation III nuclear plant.

Fusion research should continue to receive sufficient funding in order to pursue effectively both the more fundamental high-temperature plasma physics programme and the fusion technology effort, in particular in preparation for ITER.

Unit 21: Turku School of Economics and Business Administration (TuKKK)

Futures Research Centre – Projects Related to Energy Research Overview and mission

The unit is one of the research centres within Turku School of Economics and Business Administration (TuKKK). The main mission of the unit is futures studies and foresight analysis, including the development of new research tools. It aims to be interdisciplinary in its approach, seeking to integrate research expertise and analytical tools drawn from the social and natural sciences and engineering to develop more coherent perspectives for decision-making.

Scientific quality, impact and viability
The unit appears to be distinctive in Finland for its interdisciplinary, methodological approaches and policy-oriented research focus. The staff are tightly knit, and perform well as a team. The research project themes are primarily clustered around systems analysis, foresight analysis and scenario development. Topics include Climate, Business and Energy in Finland, Combining Russian Energy and Climate Policies, and Energy Policy for Sustainable Development. A total of 58 international publications have been produced; however, no PhDs were completed.

Research environment and organisation
The unit has no core funding from TuKKK, no tenured staff and no support staff. TuKKK provides basic research infrastructures. In the energy-related field, the unit has 8 FTE staff but no professor. Funding is obtained from external research contracts. The character of the research means that no large scientific infrastructures or equipment are required, although the research involves heavy use of computers and databases. The unit is perceived to operate as a rather ad hoc unit, and lacks adequate academic recognition within TuKKK.

Interaction between research and society
The mission of this unit is considered clearly defined and valuable. The nature of the research places a premium upon effective networking with a wide range of national and international organisations. National cooperation appears modest – effectively achieved by working with research students in other Finnish universities. International cooperation, for example with Russia and South-East Asia, was reviewed excellent, even outstanding, for such a small and non-tenured unit.

Recommendations
An element of core funding is now required to enhance the independent, academic character of the research, and also to provide the essential continuity not easily achieved by the current complete dependence on a succession of comparatively short-

term external grants. In addition, establishing more formal links with other academic departments would be a desirable development. This would be facilitated by the creation of a professorial post and the provision of postgraduate teaching.

Unit 22: Government Institute for Economic Research (VATT)

Department of Environment and Infrastructure

Overview and mission

VATT is a research organisation funded by the Finnish Ministry of Finance. Although undertaking independent research in applied economics, its prime function is similar to that of a 'think-tank': it evaluates the effect of government policy and generally does applied research on politically relevant topics. In the energy field VATT activities cover electricity markets, energy policy, climate policy, government policy evaluation using economic models and econometrics, as well as scenario simulations using CGE models. One of its particular strengths is the study of climate change mitigation policy on the economics of energy production and use. A highlight is the establishment of the link between consumption trends and emissions. VATT's work is facilitated by excellent access to economic data from government sources.

Scientific quality, impact and viability

The work done by the unit (Department of Environment and Infrastructure) is of a high standard, in particular in the area of forecasting with economic models and in contributing to the development of appropriate methodologies. International recognition is growing. Even though the unit does not fit into the traditional role of a research institute, the staff are encouraged to publish in appropriate international journals and there is a summer programme for graduate students. Despite this, the journal publication record in recent years has been rather modest, perhaps because the staff are over-stretched. In addition to the work of Finnish and EU organisations the unit should consider the MIT Emissions Prediction and Policy Analysis (EPPA) Model and the Second Generation Model (SGM) of the Joint Global Change Research Institute.

Research environment and organisation

VATT receives some 20% of its funds from external sources, including both the private and public sectors. External funding for energy-related research is notably higher: 30–40%.

Interaction between research and society

There is clearly a high degree of relevance for society from the very nature of the work. Potentially, the research programme of this unit can – by assisting in establishing and evaluating national energy policies – have direct effect on government thinking and legislation. The inclusion of sustainability aspects into the unit's economic models and their incorporation into government policy is of potentially major value.

Recommendations
The team's research activities should be linked more strongly with those of university-based teams, which would be of mutual benefit and help strengthen the energy policy research community in Finland. As a first step, the summer trainee training programme at VATT could be expanded. The unit was reluctant to benchmark itself against other comparable institutions or to emphasise its national and international connections. Several similar, and stronger, groups exist elsewhere in the EU and North America. Although exact benchmarking comparisons may prove difficult, given the differing research themes covered by roughly comparable units abroad, it should be attempted (e.g. against those at MIT, Princeton, SPRU/Sussex and the ISI Fraunhofer team in Karlsruhe).

Unit 23: Helsinki University of Technology (TKK) Department of Engineering Physics and Mathematics

Advanced Energy Systems – Nuclear

Overview and mission
The unit's scientific programme consists of research in nuclear fusion as well as in nuclear fission and radiation physics. The mission is motivated by education in nuclear engineering as an avenue to attract talented young people to the nuclear field, and thus help the country to maintain expertise in nuclear technology. The division of resources between the two areas fusion/fission is about 80:20 respectively. The unit has 1 professor, 6 further senior researchers, 3 other academic staff, 4 students and one technician. This is large compared to some other university departments in Finland visited by the Panel, but small by international standards in these specific research fields. The EU and thus the Finnish nuclear fusion programme have recently acquired particular significance given the recent decision to construct the next step international ITER experiment in Europe (Cadarache, France). This new reactor is intended to demonstrate the physics feasibility of a fusion power plant and to test some of the associated technologies.

Scientific quality, impact and viability
The fusion team works very successfully on the two Tokamak fusion devices – JET (Culham, UK) and the ASDEX Upgrade (Garching, Germany) – and has contributed to some of the major developments there in the last few years. The main interests of the team lie in edge physics and in plasma-material interactions. In addition, there is an active theory effort covering fast ion and turbulence studies using their own codes (ASCOT and ELMFIRE). The output of scientific papers is high, considering the size of the team and the field they work in. On the other hand, the fission and radiation physics team is far too small to make any significant scientific impact in a field in which Finland should actually be playing a leading European role (see below).

Research environment and organisation
The fusion team is closely integrated into the EURATOM programme and its activities are coordinated at the European level by the EU Commission. The resulting EURATOM-Tekes Association thus contains the fusion physics work here at TKK with some contributions from VTT and other universities (about one-third of the

whole) and the fusion technology programme at VTT, other universities and in industry (the other two-thirds). Having decided not to build its own fusion device when it entered EURATOM, Finland has put the emphasis experimentally on exploiting large facilities elsewhere. The degree of cooperation and networking at the European level is high. Outside funding is dominated by EURATOM and Tekes, which with other smaller sources account for more than 60 per cent of the research budget. There is very little industrial funding, which is due to the long time-scale for the practical realisation of fusion as an energy source.

Interaction between research and society

The fusion team has an impressive record in promoting public awareness of fusion research. Their activities encompass articles in newspapers and magazines, radio and TV appearances as well as discussions with politicians. The fission team has also been active in this respect but its small size has limited this role.

Recommendations

The fusion team should continue to concentrate on those questions, presumably in edge physics, which will probably form the backbone of its contribution to research on ITER in ten years' time. For the public perception of fusion research it may be important that this work now acquires a more visible ITER label. The impressive theory and modelling effort in preparation for ITER should continue undiminished. Fission-related research in Finland outside VTT is not strong, when one considers that the country is now taking the leading role in Europe in the construction of a new generation of nuclear power plant and in addressing the waste storage problem. The two Finnish universities that teach nuclear engineering, TKK and LUT, must have stronger research activities. A strategy should be developed with VTT on the role TKK could play in support of Finnish nuclear power plant operation.

Commissioned by the Academy of Finland, a panel of international experts was invited to evaluate Finnish energy research carried out during the period 1999–2005. This evaluation report contains statistical material on resources and outputs of the research, and an overall appraisal of the research status in the energy fields most important to Finland. In addition, an evaluation of the educational performance of the university units and reports on the individual units are presented.

The report presents the results and recommendations of the evaluation by the international expert panel. The report also includes proposals for the future development of research in the field.

ACADEMY OF FINLAND

Vilhonvuorenkatu 6 • PO Box 99, 00501 Helsinki
Tel. +358 9 774 881 • Faksi (09) 7748 8299
www.aka.fi/eng • viestinta@aka.fi