



Roles, effectiveness, and impact of VTT

Towards broad-based impact monitoring of a research and technology organisation

Torsti Loikkanen | Nina Rilla | Matthias Deschryvere |
Janne Lehenkari | Juha Oksanen | Jukka Hyvönen |
Robert van der Have | Erik Arnold

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Robert van der Have

VTT Technical Research Centre of Finland

Erik Arnold

Technopolis Ltd and the University of Twente



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VTT
PL 1000 (Tekniikantie 4 A, Espoo)
02044 VTT
Puh. 020 722 111, faksi 020 722 7001

VTT
PB 1000 (Teknikvägen 4 A, Esbo)
FI-02044 VTT
Tfn +358 20 722 111, telefax +358 20 722 7001

VTT Technical Research Centre of Finland
P.O. Box 1000 (Tekniikantie 4 A, Espoo)
FI-02044 VTT, Finland
Tel. +358 20 722 111, fax +358 20 722 7001

Foreword

Current global economic challenges underline the importance on how to turn science and R&D investments into business success, welfare, and economic growth. It has often been claimed that measuring the results of scientific investments exactly is complicated, even impossible. At the same time, it has been shown that well-selected and focused investments in science and R&D always create added value and knowledge spill-overs with positive effects, either immediately or indirectly and over time.

For VTT, evaluating the organisation's impact and productivity is important, and has become more crucial recently.

VTT is not a university, or an engineering or consultancy agency. As the largest research institute in Finland, VTT uses a significant amount of resources in generating new data, novel knowledge, and innovations. All of VTT's stakeholders want to see the outcome of the resources invested in it. Close cooperation with universities, other research organisations, customers, the public sector, and financiers gives VTT a special role in its field. It also differentiates VTT from other players. Customers justifiably expect to see results and positive impact from the money they invest in VTT's services. As part of the Finnish innovation system and operating under the auspices of the Ministry of Employment and the Economy, VTT is committed to generating societal and business benefits in line with the Ministry's strategic goals. In addition to annual performance measurement, surveying VTT's longer-term, more holistic impact is of utmost importance.

This publication is dedicated to broad-based impact monitoring of VTT, as an international competition-oriented research and technology organisation.

This study will hopefully give readers a broad view of the systematic evaluation of VTT's impact analysis and the outcomes of VTT's competencies. As a key player in the innovation economy, VTT is proud to demonstrate the results of this work and outline how systematic analysis gives us the tools to develop VTT for the benefit of our stakeholders, customers, the public sector, financiers, and end users. It should also help us develop VTT's strategic focus and research portfolio in the future.

Espoo 14 June 2013

Erkki KM Leppävuori
President & CEO of VTT

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Executive Summary

Background and objectives of study

Research and technology organisations (RTOs) are key players in the national innovation systems of many industrialised countries and they act as an increasingly recognized knowledge pool in boosting innovation and economic development in the European Union. RTOs receive basic funding for their strategic long-term research and the development of scientific competence from government. They also receive state funds for joint research funded by national agencies and EU Framework Programmes, and obtain contract research income from private and public customers. All funding sources are under pressure due to changes in the national and global economic and innovation landscape and growing performance, effectiveness, and impact pressure on research, technology, and innovation (RTI). In this context, the aim of this study is to investigate the roles, legitimacy, and socio-economic impacts of VTT Technical Research Centre of Finland.

This study has the following objectives: (1) To give a European and global perspective on the roles, rationale, and trends of RTOs, in order to set our analysis of VTT in perspective; (2) in the context of the Finnish innovation system, to explore the roles through which VTT enhances innovation performance and generates socio-economic and ecological impact; (3) to outline a toolbox of methodologies for exploring VTT's impact; (4) to carry out a quantitative analysis of innovations in the SFINNO database concerning VTT's contribution; (5) to carry out a case-study analysis of seven individual innovations involving a VTT contribution; and (6) to assess and make recommendations for topics and methodologies in VTT's impact studies in the future. VTT's roles and impact are considered in the context of major global socio-economic and technological challenges, and special attention has been paid to VTT's internationalisation and its roles in enhancing the innovation performance of small- and medium-sized companies.

Changing roles and rationales of RTOs in Europe and beyond

The major types of public research institutes are scientific research institutes, government laboratories, and RTOs primarily dedicated to supporting innovation in business. In practice, VTT is a combination of an RTO with some government labs. The three-part innovation 'model' of RTOs requires them to be well-

connected both to the scientific and industrial worlds. Market failure is the conventional rationale for public research funding and, in the case of RTOs, capability failures are a particular commonly used argument. This study identifies five drivers for change affecting research institutes and future policy needs in relation to them. *First*, the demand for institutes' RTI services is becoming increasingly sophisticated, as their customers are becoming more complex. RTOs are shifting from simple product and process development and training for less sophisticated users towards research-intensive cooperation with sophisticated users, typically helping to overcome knowledge or capability obstacles rather than trying to make and transfer complete new products or processes. *Second*, there is increasing convergence between technologies and scientific disciplines, which is giving rise to new scientific fields and 'hyphen technologies' cutting across traditional boundaries and leading to an increasingly systemic character of research. *Third*, globalisation is an important driver for change because science as such is global in nature, and for other reasons such as collaboration and competition in science and innovation, access to global know-how, and global socio-economic challenges. *Fourth*, policy is an increasing driver for change, especially in relation to the European Research Area (ERA), because European research resources need to be much more concentrated. *Fifth*, the proportion of competitive funding in the funding structure of RTOs is increasing and their 'core' or basic funding is diminishing. These changes are driven both by the political desire to share the cost of public institutes with industry and by the growth in the use of ideas from the New Public Management movement.

The following trends among RTOs can be identified. *First*, they are moving towards more basic research, university links, and upskilling their staff. The increasingly scientific basis of technology and the growing capabilities of customers are encouraging closer cooperation between institutes and universities, through things such as cross and joint appointments, Ph.D. student exchanges, and joint research projects. *Second*, the trend towards polytechnicity, the convergence of institutes' thematic specialisation, and towards a wider range of disciplines is growing, because customers' more challenging and complicated problems call for cross-disciplinary solutions. *Third*, RTOs are continuously developing their organisation and scale, as they believe that they need to be polytechnic in order to service wide-ranging customer needs, and be big enough in each of their specialities to be attractive to customers and visible internationally. *Fourth*, RTOs are looking for ways to accelerate their internationalisation by finding new customers abroad and developing their links with domestic customers that are expanding internationally. In practice, traditional RTOs have not internationalised much. *Fifth*, RTOs are widening their missions, paying growing attention to markets, and are developing their commercialisation activities to serve market needs.

VTT is the only RTO in the Finnish innovation system

VTT plays an important role in Finland's national innovation system as the largest RTO and public research organisation (PRO). Although PROs make up a large

part of research and innovation systems, they are not discussed or studied much internationally compared to universities. VTT differs from other PROs in several ways: it represents a wide range of scientific and technological expertise areas, while other PROs tend to specialise in selected socio-economic and administrative fields; the primary focus of VTT's research is in applied research but it is also strong in academic research, according to a number of scientific indicators (bibliometrics, collaboration, etc.); VTT is also moving from technology-driven programmes towards a more broadly defined mission and addressing global socio-economic challenges. Nevertheless, VTT is still treated in some governmental procedures and plans in the same way as PROs, as is the case now as part of current proposals to merge various PROs into larger units.

VTT's basic mission, strategy, and organisational structure parallel those of other Finnish PROs and European RTOs – and are articulated in the Act and Decree of VTT and gain concrete form in the performance management procedures and annual performance contracts between the Ministry of Employment and the Economy (MEE) and VTT. VTT's roles are related to various dimensions, such as networking and the coordination and combination of scientific expertise along various phases of innovation processes, accelerating the application of new technologies, and the future dimension of RTI development.

High quality is essential for credible R&D services, strategic research, and competencies

The high scientific quality of VTT's R&D and innovation services is an important criterion for the credibility of its customer services and for government as well, because basic funding is granted to VTT not only for long-term strategic research, but also to develop high-level scientific competences to enable VTT to offer qualified research services. In comparison with Finnish universities and PROs, the quality of VTT's research is among the highest in Finland. For example in terms of its publications between 2006 and 2008, VTT scored fourth-highest in a citation index comparison of Finnish research actors. Moreover, the proportion of VTT's scientific publications in the top 10% of the world's most-cited publications was the second-highest figure in the same comparison. VTT has benefited increasingly from domestic collaboration and even more so from international collaboration in terms of citations. In addition, the share of joint publications co-authored with international partners has steadily increased (from 25% in 1990–1993 to 42% in 2006–2009). Bibliometric figures indicate that RTOs such as VTT can contribute to basic research even though their main role is in applied research.

Contract research is key in commercial research services, with IPR and spin-offs increasing

Knowledge transfer via the commercialisation of research results is among the key strategies of applied RTOs such as VTT. The most important channel for the

commercialisation of research results at VTT are contract R&D services (€80 million or 30% of turnover in 2012). VTT has roughly 1,500 clients, the majority of which are Finnish companies, but there is a clear trend towards more foreign clients (25% foreign companies in 2012). Roughly half of VTT's national and international private clients are SMEs at the moment. A second commercialisation channel runs via IPRs and their sale or licencing. VTT is among the most active Finnish players in patenting technologies. VTT's annual IPR income has doubled during the last five years (€2.1 million in 2012). A third channel to commercialise VTT's research runs via its feed into entrepreneurial activities. The VTT Ventures Ltd. subsidiary uses technology and IPR created by VTT to set up spin-off companies and infuses these start-ups with complementary knowledge from its network of incubators, accelerators, mentors, trainers, and venture and angel capital investors. VTT Ventures has invested in 23 companies that have raised overall capital of €15 million to date.

Extension and diversification of internationalisation activities are key challenges

RTOs are part of the global scientific community and affected by and integrated into global scientific and technological development. Research collaboration in EU programmes represents the largest part of VTT's international activities, and VTT had the largest share of funding of Finnish research organisations in EU's framework programmes in 2011. VTT has a very good European ranking (12th in 2011) in terms of attracting European project funding, and has a good networking activity and reputation (ranked 6th in 2011). VTT's revenue from overseas amounted to 18% of all revenue in 2011, of which 11% was EU programme project funding. VTT also has the highest volume of foreign company funding of any Finnish PRO. VTT's impact on internationalisation takes place not only in direct RTI collaboration but also via the transfer of acquired and absorbed knowledge in projects to Finnish clients, aimed at strengthening the competitiveness of Finnish companies in international markets. VTT has also developed new forms of international activities, such as the Kemira Corporation's and VTT's joint R&D centre in São Paulo, Brazil, and the Joint Institute for Innovation Policy (JIIP), a joint venture between VTT, TNO, Joanneum Research, and TecNALIA that provides support to policy-making in research and innovation policy, particularly for the EU. VTT also has an impact on European policy-making through its active participation in the European Association of Contract Research Organisations (EARTO).

Innovations are an important complementary indicator in impact assessment

The industrial, socio-economic, and ecological impact of research investments emerge via the innovation outputs of both existing and new companies and via changes in their subsequent performance and size. The knowledge generated subsequently can spill over via existing or new networks. Impact assessments are usually based on company-level data ('subjects') collected via R&D surveys. Data

on individual innovations ('objects') is typically missing from traditional impact analysis. Innovations may be considered as a conduit for output from research funding generating socio-economic and ecological impact, and, as a result they are among the key indicators of impact of research funding, complementing traditional indicators. VTT's SFINNO database provides an opportunity to analyse the role individual innovations play. This database contains roughly 5,000 significant innovations commercialized between 1945 and 2009 by Finnish companies and represents a body of data for assessing VTT's role in and contribution to the development of the innovations made by Finnish companies.

VTT contributes to highly complex innovations, core technologies, and commercialisation

Analysis of the SFINNO database of innovations has provided us a number of insights into the role of VTT in nurturing Finnish innovations. First, it appears that VTT is an important collaboration partner for companies that have developed innovations that they have subsequently launched commercially. During 1985–2009, VTT collaborated in around 34% of all observed innovation projects, and this percentage remained stable during the entire period. In comparison to other types of potential partners for Finnish innovators, VTT is the second-most important innovation partner after all 10 Finnish universities, as they are counted together. Furthermore, VTT increasingly contributes to innovations through its own in-house R&D and has been responsible for almost 3% of Finnish innovations in recent times. As a collaborative partner and provider of expertise and know-how, VTT's role is considered especially important in the development of highly complex innovations; VTT's significance is even higher in respect of more novel innovations. Another question that we looked at is the type of know-how behind innovations in which VTT played a role in their development compared to innovations in which VTT played no part. Here, it appeared that a significant role was most often found when developing companies' core technology and production methods, both of which are considered strategically important. Given the small home market for Finnish innovators, export is a crucial objective. Here, we observe that since 2005, innovations in which VTT has played a role have been internationalized slightly more frequently than those where VTT was not involved in development work.

VTT's diverse roles are manifested in the analysis of individual innovations

Seven empirical case studies of industrial innovations involving a contribution from VTT shed light on VTT's diverse roles in the various phases of the innovation processes of Finnish companies. These cases exemplify the significance of focused long-term research in developing competencies that are critical to new solutions for VTT's industrial customers. In order to be able to bring added value to industrial customers, VTT's commitment to strategic long-term research in scientific and technology areas important for future industrial development is crucial. The socio-economic and ecological impact of these long-term strategic commit-

ments emerges after innovations are commercialised. For example, environmental or health benefits are the sum of various factors driven by market demand or regulations, and it is often difficult to attribute final impact to one specific innovation.

Towards broad-based monitoring of VTT's roles, effectiveness, and impact

This study considers various approaches and methodologies in analysing the effectiveness and impact of research in general and of RTOs in particular. The study introduces the general framework of impact and effectiveness assessment and analyses multiple quantitative and qualitative methods to assess the impact of research, the different categories of impact, and the key challenges facing impact analysis. The study also makes a general suggestion for a roadmap of future practices in assessing the impact of VTT, and concludes by suggesting the launch of a new series of studies focusing on the analysis of the different aspects of VTT's impact on the Finnish economy and society. To provide the maximum utility, these studies would benefit from the collection of better data and the use of the latest evaluation methods.

In conclusion, private and public research, technology, and innovation funding is under growing pressure, and this is placing increasing demands on RTOs and other public research organisations to assess their performance, effectiveness, and impact. The question is whether, in times of global economic change, they will be able to retain their position in the economic and innovation systems of the future on the basis of their traditions and their ability to adjust to changing environments. It may be appropriate here to quote a 1989 OECD study on the changing role of government laboratories, which concluded: "Government research establishments never die, they survive through various transformations while at the same time retaining a strong sense of tradition."

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1. Introduction: background and objectives

The activities of research and technology organisations (RTOs) are of increasing importance to the European innovation system. Their overall annual impact has recently been estimated to be in the range of €25 to 40 billion, whereas their 10-year or mid- to long-term social returns are in the order of €100 billion (Technopolis Group 2010). Micro and macro data indicates that specialisation in high-technology sectors is one of the key factors offsetting the effect of the economic downturn on corporate innovation investments across Europe (Filippetti and Archibugi 2011). Despite the pivotal role that RTOs play in the innovation system, they have been under mounting pressure. As the financial crisis unwinds, RTOs are being increasingly confronted with institutional reconfigurations, increased competition, and demands for greater social responsibility. Moreover, RTOs face various other challenges linked to their legitimacy, roles, and financial status. These challenges arise from the key roles that knowledge and innovation have in solving large socio-economic challenges, changes in the role and nature of research communities, pressures on public funding and resulting requirements for higher efficiency and effectiveness in research, as well as the challenges of internationalisation for national research communities (PREST 2003, SPTC 2008, EC 2008, OECD 2011).

This report will focus on how VTT Technical Research Centre of Finland (VTT) addresses this dilemma. The current challenge for VTT relates to three related trends. A major issue affecting the operational environment of VTT is the reform of public research institutes. A proposal on this was published by government in 2012 and has been under debate since then. Specific recommendations for VTT were recently released in a report commissioned by the Ministry of Employment and the Economy (Saarnivaara 2013). A second trend concerns the need for increasing cooperation as a means of addressing growing international competition. The latest results from VTT's customer survey indeed show that it is mainly foreign RTOs that are seen as VTT's competitors, rather than Finnish universities. A third trend concerns the fact that the use to which tax-payers' money is put to today has to be increasingly justified.

VTT is a public research organisation dedicated to producing research services that increase the performance of companies and society. VTT's activities primarily embrace R&D, but also technology transfer and testing, and it acts as a non-for profit organisation offering services based on a commercial pricing system. To

ensure the maximum impact of its activities, VTT has a long tradition of both internal and external evaluations (Lähteenmäki-Smith et al. 2006, Loikkanen et al. 2011, Niinikoski et al. 2010). In addition, VTT carries out evaluations of its programmes and strategic research areas (see references section). The most recent external VTT evaluation revealed that the main strategic challenge lies in transforming VTT from a national institute into a truly international player. VTT needs to be able to meet global ambitions of big industry and pay more attention to commercialisation. Based on these challenges facing VTT and taking into account its tradition of continuous assessment, we advocate a new generation of impact studies (“VTT’s IA analysis plan for the future”), of which this study is the first.

The main focus of this study is on the legitimacy of VTT and justifying the basic funding that it receives from government. Three objectives will be addressed: to develop a toolbox of the most recent methodologies to explore the impact that VTT has; to assess the various roles that VTT has; and to carry out pilot studies applying selected approaches and methodologies for pinpointing future good practices for VTT impact studies. The analysis will be made in the context of the current strategy of socio-economic global grand challenges and will pay attention to the internationalisation of VTT and its importance for SMEs.

The study is structured as follows. Chapter 2 gives an overview of the European RTO landscape and the challenges it faces. Chapter 3 introduces the goals, legitimacy, and roles of VTT in the national research and innovation system. Chapter 4 reviews various impact models and summarizes a toolbox of the most recent methodologies for studying impact. Chapter 5 looks at the quality, commercialisation and internationalisation of VTT’s research activities, and Chapter 6 looks at the role that VTT plays in R&D cooperation for Finnish innovation. Chapter 7 provides case study evidence of VTT’s different roles, and Chapter 8 outlines some conclusions and formulates various recommendations.

2. Perspectives on the role and rationale of RTOs in Europe and beyond

This chapter will provide an overview of the current developments in research and technology organisations (RTOs) by way of background for a more detailed consideration of VTT. We will look at how RTOs differ from other government research institutes and why it makes sense for the state to fund RTOs. The chapter will then look at the major forces affecting RTOs internationally and the changes that they are resulting in. The chapter concludes with an assessment of the 'intervention logic' for the core funding of RTOs, describing the chain of interlinked effects that are expected to result from funding and the operation of an RTO. The balance of this report explores some of these linkages as they operate at VTT.

2.1 What are research and technology organisations?

Government research institutes, or public research institutes as they are also known, represent a composite category. Their history suggests that there are three major types (Arnold, Clark & Jávorka 2010), two of which can readily be subdivided:

- Scientific research institutes
 - carrying out science that could also be done in a university
 - carrying out science that is dependent on large-scale or expensive equipment
- Government laboratories
 - producing knowledge needed for legislation and regulation
 - producing public goods on behalf of the state
- Research and technology organisations dedicated to supported innovation in business.

In practice, VTT is a combination of an RTO with some government labs.

Historically, some scientific research institutes have their origins in research councils or academies of science that were both sources of funding for research and carried out research themselves. In many parts of Western Europe, the fund-

ing and research functions of research councils have been separated. In the former Soviet bloc, academies of science tended to control their own institutes up to the end of the 1980s. Those that owned institutes acting as external R&D departments for factories have generally privatised or closed these organisations. Some have split off the remaining more scientific institutes or transferred them to universities; in others, academies continue according to the former integrated model.

A second category of research institutes – often but not always referred to as ‘government laboratories’ – focuses on producing public goods to meet the knowledge needs of the state or wider society. Sometimes referred to as ‘sector’ institutes, specific government ministries generally own these organisations and their main function is normally to deliver services and policy-relevant information to government. Examples include nuclear research, marine institutes (which combine counting fish stocks with more fundamental work on marine biology), and metrology. The work of these laboratories often includes extensive routine service or monitoring activity for government, which is not R&D but which is supported by their research.

The third category of RTOs or ‘applied industrial research institutes’ tackles the needs of industry for knowledge and a range of knowledge-related services. Their origins are often as testing laboratories, product and process developers for industry, or branch-based research associations. They focus on user- or problem-orientated research for the benefit of society and normally win the majority of their funding competitively. In most countries, the state has taken over from branch research associations as the patron of RTOs. Typically, their role is to assume some of the risks of industrial innovation, helping companies go beyond what they would otherwise be able to do based on their in-house technological capabilities. RTOs internationally tend to have at least one of three types of origin.

1. Research associations, which originally tackled common problems within one or more branches of industry and then developed into institutions,
2. ‘Technology push’ institutes, set up to promote industrial development. VTT is a mixed case where a policy decision was taken to transform a services-focused institute into a technology push institute, and
3. Services-based institutes, which generally focused initially on measurement, testing, and certification. These have tended to move ‘upstream’ into research.

Other factors can also play a role in RTO development. In some cases (e.g. TNO), a defence mission was partly integrated. Sometimes, as with Seibersdorf Laboratories in Austria, providing a home for nuclear energy research was a factor.

2.2 Why the state funds RTOs

RTOs operate with the support of the state because they generate societal benefits that the marketplace cannot produce. The need for state funding is rooted in

the economics of knowledge, which is a 'non-rival' good that many people can consume without it ever becoming used up. It is also 'non-excludable', in that it is hard to stop people accessing it. Non-excludable, non-rival goods are 'public goods'. Entrepreneurs will not generally produce things that people can consume without paying for them. It makes sense for the state to invest in public goods, however, because the returns go to society as a whole. This is why basic research is fully funded by the state in most countries. The closer knowledge is to a specific application, the fewer potential users it has and the more its application involves complementary investments, in specific designs and production facilities, for example. Because these things can be owned or monopolised, private investment becomes attractive, so most industrial R&D is privately funded. Benefits from private R&D also tend to spill over to society over time – both through the innovations that are generated and through the 'leakage' of knowledge into other areas in the form of information and through people changing jobs.

This idea that companies are reluctant to invest in public goods underlies the conventional 'market failure' justification for the government funding of research (Nelson 1959; Arrow 1962), which assumes that there is under-investment in research compared to a welfare-economic optimum. However, there is no 'iron rule' that prevents companies from doing or paying for basic research. They sometimes do, and in the past they probably did so to a greater extent than today (Rosenberg 1990; Godin 2006).

The market failure idea underlies not only state funding for basic research but also a range of other types of state R&D funding that give companies incentives for doing or paying for research that is likely to have high spill-overs. Such work is typically more risky than the R&D in which companies would normally prefer to invest. In principle, subsidies compensate companies for increased spill-overs and risks. The higher these are, the greater the funding role of the state. The easier that it is for the private sector to appropriate the benefits of R&D, the lower the rate of subsidy.

RTOs often also address 'capability failures', namely areas where there are limitations in companies' ability to act for themselves in the perfect way imagined in economics textbooks, because they either lack specific knowledge or specialised facilities.

RTOs typically work with a three-part innovation 'model' that requires them to be well-connected to both the scientific and the industrial worlds.

1. Exploratory research and development to develop an area of capability or a technology platform. This involves applied research. To do this well, an RTO has to be involved in the relevant international scientific networks, which typically requires cooperating with universities,
2. Further work to refine and exploit specific knowledge or a specific platform in relatively un-standardised ways, often in collaborative projects with industry, and
3. More routine exploitation of knowledge, including via consulting and providing services.

In principle, RTOs' core or basic funding is primarily intended to pay for the first, exploratory stage, where a RTO develops the knowledge and capabilities needed to support its industrial customers. This is the key factor that distinguishes an RTO from a technical consultancy, which normally does not have the resources to operate in advance of its customers' needs. Public money is used to create the capabilities that the institute needs to take companies 'one step beyond' what they could otherwise do, thereby providing social returns by de-risking innovation (Sörlin et al. 2009).



Figure 2.1. Shares of international co-publications in the output of Nordic RTOs. Source: Solberg et al. 2012.

Industrial applied research institutes in the Nordic region additionally play a very important role in internationalising each country's research and innovation system, as can be seen from the high share of international co-authorship in their publications seen in the Web of Science. The proportion of internationally co-authored papers in VTT's output is significantly higher than that of Finnish universities, which is 29% (Treuthardt & Nuutinen 2012). They achieve this partly because they are major participants in EU Framework Programmes and partly because a key part of their role is to interact with global science and technology and make the results and capabilities that are generated available to national industry.

2.3 Forces acting on research institutes

A major recent study of European research institutes (Arnold et al. 2010) combined historical case studies with a foresight exercise to identify the forces for change acting on institutes and to identify future policy needs in relation to them.

Increasingly sophisticated demand. Institutes' customers are becoming increasingly sophisticated over time. As industrial development proceeds, production becomes more technology-intensive and people throughout society become more involved with knowledge production as more and more of them receive high-

er education. As a result, industrially orientated RTOs do more demanding research, as some of their knowledge becomes more commonplace and can be delivered by the private sector. Other types of institute also face potential demand as capabilities increase. Over an extended time frame, this means that RTOs move away from simple product and process development and training for unsophisticated users towards research-intensive cooperation with sophisticated users, typically helping overcome knowledge or capability obstacles rather than trying to make and transfer complete new products or processes.

Convergence. There is increasing convergence among technologies and between scientific disciplines (MIT 2011). This has given rise to scientific fields such as bioinformatics, systems biology, evolutionary medicine, computational linguistics, and cognitive psychology. A second convergence under way is towards 'hyphen technologies' (micro-electronics, bio-technology, etc.) that cut across previous boundaries. More generally, growing technological complexity means that research has an increasingly systemic character.

Globalisation is an important change driver in the institute world, as elsewhere. Scientific research institutes share scientists' more general propensity to cooperate internationally, especially in 'basic' disciplines and in small countries. There are also extra-scientific reasons, such as former imperial links or mobility patterns (Frame & Carpenter 1979). There is clear and continuing growth in international scientific collaboration (Wagner & Leydesdorff 2008; Adams et al. 2007), although the rate of growth seems now to be tailing off, suggesting the approach of some kind of natural limit. Other motivations for international cooperation in the research community highlighted in the literature include (Archibugi & Lammarino 1999; Beaver 2001; Wagner 2006; Edler et al. 2007):

- Access to leading edge and complementary know-how
- Combination of competences and data located in different countries to tackle issues too complex for researchers at one location
- Finding solutions for complex scientific and technical problems that cannot be solved using solely domestic resources
- Cost and risk sharing, especially when extensive infrastructure is needed for basic science (e.g. particle accelerators) or product development (e.g. international telecommunication networks)
- Access to funds
- Recruitment
- Access to research subjects or data that are geographically specific,
- Access to markets
- Influencing regulatory regimes or standards, and
- Improving the impact and visibility of one's research.

Policy. The effort to generate a European Research Area (ERA) means that European research resources will need to be much more concentrated. The European Commission is taking its mandate to 'structure' the ERA seriously, so EU-level incentives may well appear for cross-border restructuring. To date, EU policy

influence over national government laboratories has largely been limited to supporting the creation of EU-wide associations and involving them in the Framework Programme. RTOs could become more important to the ERA, but are largely locked nationally through their funding arrangements (ERA Expert Group 2008). There is still no real common market in research services (even if successful RTOs, notably VTT, SINTEF, TNO, GTS, and Fraunhofer now obtain a significant part of their industrial income from cross-border sources). Government laboratories increasingly confront task duplication, a need for specialisation, a re-division of labour, and in some cases closure of duplicate facilities, for example in meteorology (Barker et al. 2012).

Core funding. There is a trend in the way that states fund institutes towards increasing the proportion of competitive funding and reducing the automatic 'core' funding that they receive – as well as towards placing increasing demands (in terms of performance indicators) on how core funds are used. These changes result both from a political desire to share the cost of institutes with industry and from the growing popularity of the ideas of the New Public Management movement and its mission to seek better monitoring and measurement of the use of public funds.

2.4 Trends among institutes

These factors are driving the following trends among institutes.

More basic research, university links, and upskilling of staff. The increasingly scientific basis of technology and the growing capabilities of customers is seeing closer cooperation between institutes and universities such as cross and joint appointments, Ph.D. student exchanges, and joint research projects. Institutes have more Ph.Ds. on their staffs and publish more in peer-reviewed journals than before. They also co-publish more with others, especially universities. At the same time, universities are under pressure to adopt a 'third mission' of supporting society and the economy. As a result, some universities are now trying to compete not only with scientific institutes but also with RTOs in delivering services to industry (Arnold et al. 2007).

Polytechnicity. The trend to convergence means that institutes' thematic specialisation has to evolve, driving them towards a wider range of disciplines, especially but not only in the RTO domain. Users' increasing capabilities pose more difficult and complicated problems, which typically need cross-disciplinary solutions. As a result, there has been a long-standing drive towards larger, more polytechnic RTOs. This process first began to be seen 20 years ago (Skoie & Ødegård 1990).

Organisation and scale. RTOs increasingly believe that they need to be polytechnic in order to service wide-ranging customer needs, and big enough in specific fields to be attractive to customers and visible internationally. Some smaller and more fragmented systems have been consolidated, as has happened in Norway, Sweden, and Austria, for example.

Sweden has moving to a single system of RTOs and government laboratories. The Industry Ministry has successively encouraged mergers and created a structure of four fairly large, technology-based (as opposed to branch-based) institutes. The recent policy proposal in Finland would have the same effect. The Austrian Institute of Technology has been created as a conglomerate based on the Seibersdorf institute, to which others (such as Arsenal) have been added. In Denmark, the country's GTS institutes – which, although not commonly owned receive their block funding through the GTS umbrella organisation – have successively merged, halving the number over the past decade. At the large end of the spectrum, however, organisations have not tended to grow in recent years, except for Fraunhofer, which expanded into the former East Germany and is now growing internationally.

Internationalisation. RTOs would ideally diversify geographically, to keep in touch with their customers as they expand internationally. Other institutes may do better by building scale at one location. IMEC has shown that there can be large local benefits when an institute builds an internationally strong position, sucking in research employment, capabilities, and knowledge that benefit the local economy (Sörlin et al. 2009). In practice, traditional RTOs have not internationalised much. In the current situation, where they are funded by individual countries, there is little external incentive for internationalisation. In contrast, privatised RTOs, such as Qinetiq and PERA in the UK and IABG in Germany, have set up multiple offices abroad. Generally speaking, international cooperation is increasing across the entire PRI sector.

Widening missions, growing importance of markets. The need to diversify income sources is driving institutes (especially government laboratory) to address new customer groups. The debate in recent decades about the role and ownership of government laboratories means that commercialisation missions have often been added to their duties. These include spin-out, selling intellectual property, joint or contract research with large companies, transferring knowledge to small companies (through the widely copied US SBIR programme, for example), and industrial extension. As a result, government laboratories are becoming more and more like RTOs.

2.5 Expected impact

Since the overriding purpose of RTOs is to promote industrial competitiveness, they can only do their job if they are technologically capable and can offer customers inputs that are in advance of or otherwise superior to those available on the commercial knowledge market. Core or 'capability' funding exists in order to fund this. An institute's technological advantages are passed on to its customers, whose performance improves, become more competitive, employ more people, pay more taxes, increase people's quality of life, and so on.

Figure 2.2 summarises the overall logic for the state to intervene in the innovation system by investing in RTO funding. The rest of this report explores some of these links to impact as they relate to VTT.

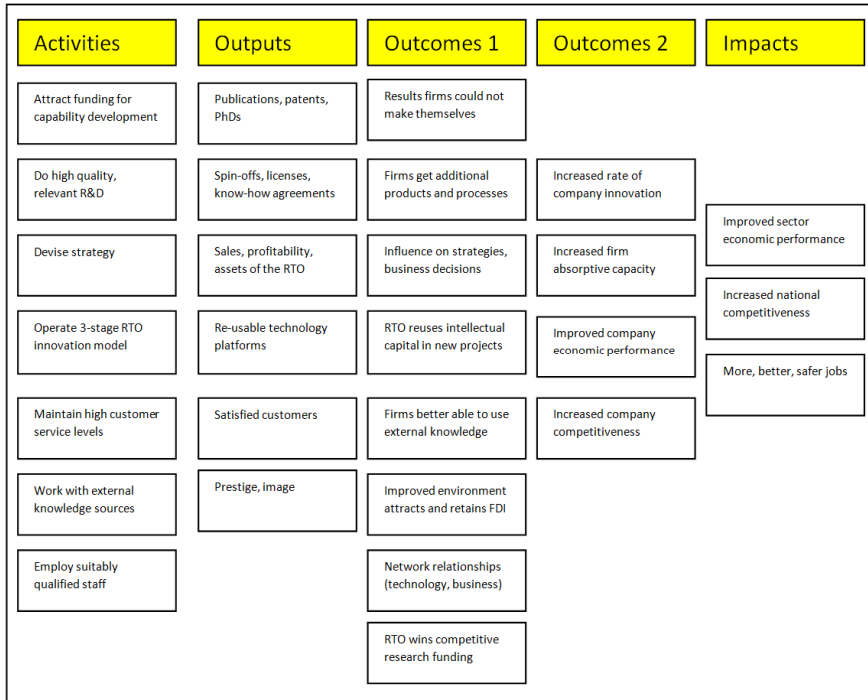


Figure 2.2. Logic diagram for institute funding.

3. Role and rationale of VTT in the Finnish innovation system

This chapter considers the status, role, and rationale of VTT in the Finnish research and innovation system. VTT is considered in the context of Finnish innovation policy by examining recent changes in policy and how VTT has responded to these changes in its strategy, management, organisation, and funding.

3.1 VTT in the Finnish research and innovation system

VTT is the major resource for innovation in Finnish industry and society. Figure 3.1 gives an overview of the key public decision-makers, financiers, and actors in the R&D world, including VTT, in Finland. Operating under the auspices of the Ministry of Employment and the Economy, VTT and Tekes – the Finnish Funding Agency for Technology and Innovation are among the key innovation policy organisations in Finland in their capacity as an R&D organisation and an R&D funding organisation respectively.

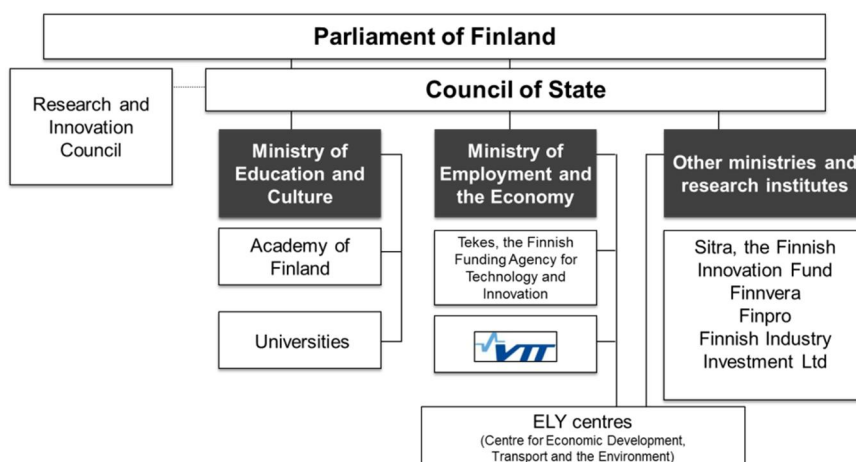


Figure 3.1. Key public decision-makers, financiers, and R&D actors in Finland.

VTT is by far the largest of Finland's research institutes, and with around 3,000 staff is also large internationally, both in absolute and per capita terms. Due to its extensive technological expertise, VTT is comparable to similar large national research and technology organisations in Europe, such as Fraunhofer Gesellschaft (FhG) in Germany, TNO in the Netherlands, and the Austrian Institute of Technology (AIT) in Austria. Public research organisations like these make up a large part of most research and innovation systems, but compared with universities they are not much discussed or studied internationally. There is a small 'grey' literature on them, but very little in the 'white', peer-reviewed literature. They are "the neglected stepchild of public policy" (Crow & Bozeman 1998). In 2012, Finnish institutes collectively had a budget of about €300 million from the state, amounting to 15% of government research spending (compared with €575 million in government research funding that went directly to universities through their core funding). Institutes obtained a further €300 million in external research income, making their aggregate income about €600 million. VTT accounted for almost half of this amount.

To some extent, research institutes are ignored in Finland as well. Despite the amount of science they do, they are barely mentioned in the Finnish Academy's new report 'The State of Scientific Research in Finland 2012' (Treuthardt & Nuutinen 2012), for example. On the other hand, they receive significant policy attention. Both government institutes and universities received small budget increases between 2011 and 2012, while Tekes and the Academy of Finland both had their budgets cut¹.

VTT differs from other public research institutes in several ways. VTT is a multidisciplinary organisation representing practically most scientific and technological expertise areas, while other PROs tend to be specialised in research on selected socio-economic and administrative sectors (see e.g. Loikkanen et al. 2011). Most basic research in Finland is carried out in universities, and the primary focus of VTT's research services is on applied research. As recent scientific indicator data indicate (e.g. Solberg et al. 2012), VTT's staff is active in academic research, and scientific competences are fostered by close university collaboration. VTT carried out around 300 joint research projects with Finnish universities in 2011, for example (sources: VTT calculations; Solberg et al. 2012).

Government research institutes have been the subject of a special study for Finland's Research and Innovation Council, which argues that their current orientation towards individual sector ministry interests is out of date in the context of today's global challenges and that they should be reorganised into larger, more polytechnic entities, with a few merged with universities. The rest should have access to strategic research funding, some of it disconnected from their 'sector' missions, in order to improve or maintain quality and encourage them to carry out more longer-term research than is needed to satisfy the short-term needs of their

¹ http://www.stat.fi/til/tkker/2012/tkker_2012_2012-02-24_tie_001_en.html

sector masters (Lankinen et al. 2012). This proposal is consistent with the wider trend in Finnish research and innovation policy in recent years, which has seen a reduction in the emphasis on specific technologies and technology programmes in favour of more broadly defined missions and societal challenges (OECD 2012; Solberg et al. 2012).

Finland is a country with has a strong, but not dominant research institute sector (Figure 3.2). There is a long-running international trend towards increasing the share of state-funded R&D undertaken in the higher education sector, with a corresponding reduction in the share going to institutes (Arnold et al. 2010). This trend has also been felt in the Nordic area. The merger of many government laboratories in Denmark into the university system is responsible for the dramatic change that has taken place in the Danish system, for example. Finland, the Netherlands, and Norway have retained a policy of maintaining a strong institute system focusing on applied research and development (Figure 3.3); while Sweden has consolidated and strengthened its rather small, applied industrial research institute system and slightly increased its core funding in recent years.

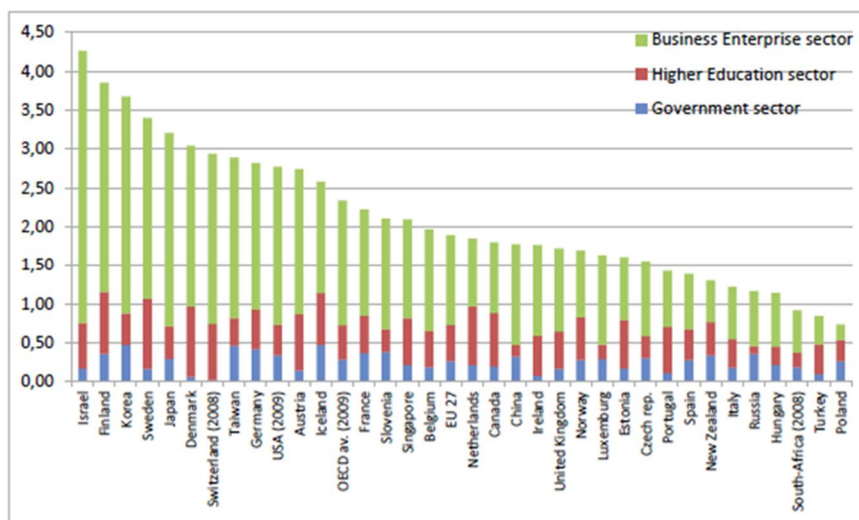


Figure 3.2. R&D by performing sector as a percentage of GDP. Source: Solberg et al. 2012; Data from OECD MSTI 2012-1.

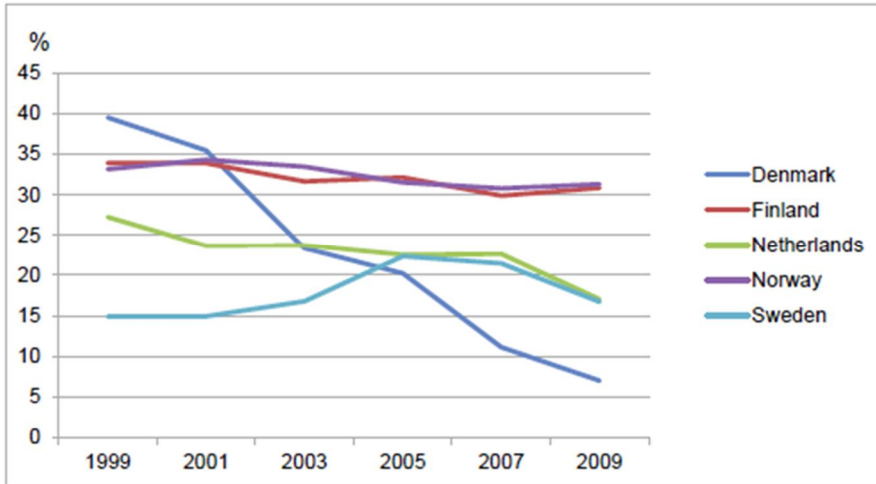


Figure 3.3. Share of public R&D expenditure in the government sector (GOVERD), 1999–2009. Source: Solberg et al. 2012; Data from OECD MSTI 2012-1.

The Community Innovation Survey reveals that research institutes are especially important for industry in Finland because companies are more dependent on external innovation partners than is the case in the other Nordic countries or the Netherlands (Figure 3.4). VTT is therefore key to sustaining innovation in Finland.

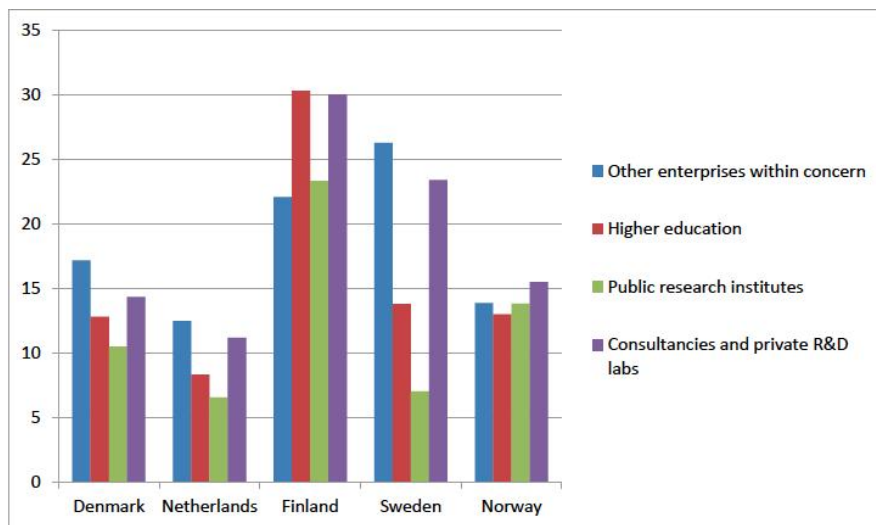


Figure 3.4. Share of innovative companies with innovation cooperation, 2008–10. Source: Solberg et al. 2012.

3.2 Tasks, legitimacy, and impact of VTT

Within the context of the general discussion of RTOs' roles, perspectives, and research funding in Chapter 2, this chapter will discuss these issues with reference to VTT. In Finland, as in other industrialised countries, public research organisations have been established to fulfil the research needs of public administration bodies. As Loikkanen et al. (2011) argue, a starting-point for the establishment of research activities of various government administrations has been a sector-specific shortage of research in areas of imperfect markets to support policy-making and eliminate negative externalities through science and technology. From the perspective of policy rationale, the essential question in the Finnish context is whether PROs (among other types of publicly funded research bodies) fulfil the criteria for public funding (ibid).

The establishment of VTT was a special case compared to other Finnish PROs. During the late 1930s and early 1940s, the general emphasis internationally was on harnessing research to support defence industries, particularly in the area of advanced material testing (Michelsen 1993). According to the Act of VTT (16.1.1942), VTT is defined as an independent research institute under the Ministry of Trade and Industry with the task of carrying out technical research for scientific and general utility purposes. In addition, VTT's responsibilities included testing materials and the structures of the authorities and private individuals or communities and carrying out contract research.

The starting-point in considering VTT's current status are the mission, objectives, and tasks given by the Ministry of Employment and the Economy (TEM). VTT's objectives and tasks are defined in the Act on the VTT Technical Research Centre of Finland (953/2010) and the VTT decree (Decree by the Government of Finland on VTT Technical Research Centre of Finland, 1012/2010), which provide a context for a more detailed definition of the institute's operational, organisational, and managerial activities.

Box 3.1 VTT's objectives and tasks according to the 2010 Act (953/2010)

The objectives of the Research Centre are to create high-level scientific and techno-economic knowledge and know-how and to generate technology and innovations for industry, commerce and society. The Research Centre improves its clients' technological and economic competitiveness and promotes socio-political planning and execution.

The tasks of the Research Centre are to: (1) perform multitechnological research and chargeable services, (2) commercialise research results, (3) provide technology development and utilisation services, and (4) provide conformity assessment.

The Act defines VTT as an impartial, non-profit expert organisation acting independently in respect of its customers. The Ministry of Employment and the Economy gives VTT the freedom to organise its operational, organisational and managerial activities, while the ministry's role is mainly to provide favourable conditions for VTT to operate and produce services for its end-customers, which include both private enterprises and public organisations. Box 3.2. describes the performance management and agreement procedure between the ministry and VTT.

Box 3.2 Performance management of the Ministry of Employment and the Economy (MEE)

- The MEE Group strategy is based on the focus areas of the government programme and is reviewed annually.
- The strategy provides the basis for integrating VTT's strategic goals into the Ministry's goals in the form of performance targets, which are included in VTT's four-year performance agreement.
- The Enterprise and Innovation Department is responsible for the performance management of VTT.
- The performance agreement includes targets concerning VTT's societal impact, operational performance, and indicators used for monitoring targets.
- VTT reports semi-annually on its progress on performance targets to the Ministry.
- The Ministry prepares an annual assessment of VTT's success in meeting its performance targets.
- A mid-term evaluation of VTT's performance is carried out after two years and a final evaluation after four years from the beginning of the agreement.

VTT's mission is to "produce research and innovation services that enhance the international competitiveness of companies, society and other customers", and to "create the prerequisites for society's sustainable development, employment and wellbeing²". As a result, VTT's basic rationale resembles that of public research organisations in general, as concluded by the OECD (2011). Although the basic rationale for these organisations varies, it is typically related to supporting the growth and productivity of industry, conducting research of benefit to society, and carrying out policy-relevant research.

VTT's core processes are commercial contract research for private and public customers and strategic joint research funded by government. VTT allocates basic funding as additional input to joint research and to internal strategic research and competence development. Three funding baskets – basic funding from govern-

² Source: VTT's presentation slides 2012.

ment, joint research with industrial and research partners, and confidential contract research – are linked to each other, and accountability in respect of these funding sources varies. The legitimacy to basic funding from government is redeemed if VTT generates sufficient socio-economic and ecological impact to justify public funding. The criteria used when planning how to allocate basic funding to different STI areas are public goods, externalities, and market and system failures, and the identification of STI areas fulfilling these criteria can be supported by roadmaps, foresights, and other forward-looking analysis. The ultimate legitimacy for basic funding is given by empirical evidence of socio-economic and ecological impact as examined and indicated by impact assessment methods, as will be discussed in Chapter 4. Figure 3.5 presents the recent strategic research portfolio identified by VTT's strategic research.

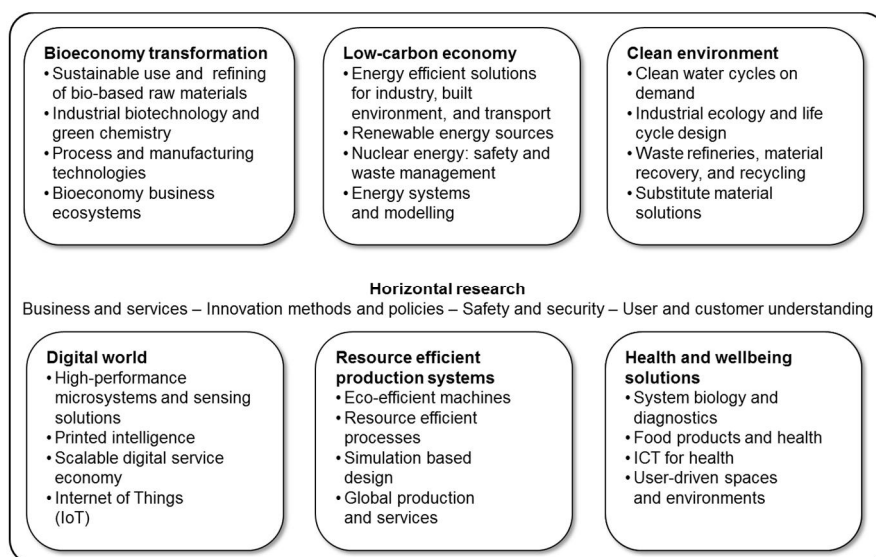


Figure 3.5. VTT's strategic research portfolio. Source: VTT.

3.2 Overview on VTT's various roles

VTT's various roles arise from the VTT Act (953/2010), the VTT Decree (1012/2010), and VTT's strategic and operational activities based on these documents, as discussed in Section 3.2. VTT has various roles in developing Finnish industrial innovation and enhancing national socio-economic welfare (e.g. Oksanen 2003; Niinikoski et al. 2010). Figure 3.6., VTT's current operational and management model, illustrates the various roles of VTT's different organisational units.

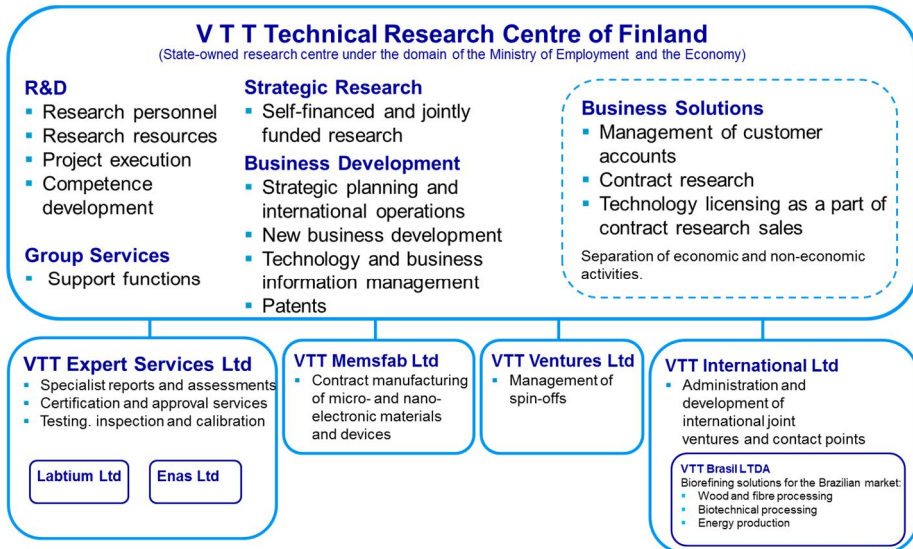


Figure 3.6. VTT Group structure 2013. Source: VTT.

As Niinikoski et al. (2010) note, the emphasis of VTT's roles vary, depending on whether they are examined from the perspective of VTT researchers, management, customers, or its partners. The authors of this study compiled the roles of VTT on the basis of the information contained in VTT's various official strategic and operational documents (Figure 3.7).

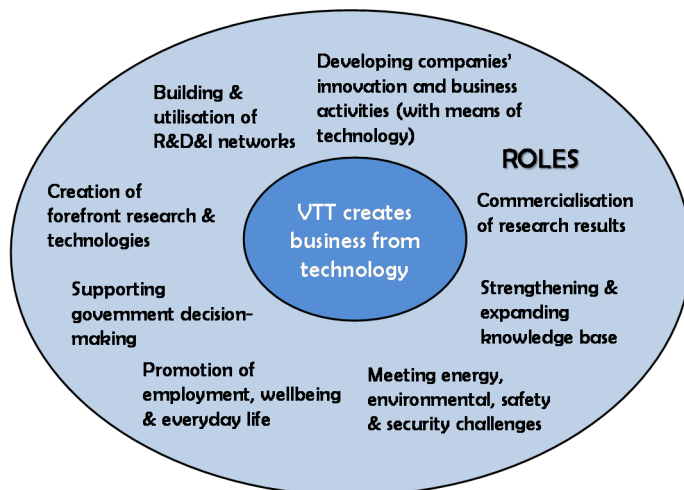


Figure 3.7. Various roles of VTT as identified by VTT's official documents Source: VTT's roles as collected from various VTT sources by the authors.

As in the analysis of Tekes' roles in the SFINPACT analysis (Hyytinen et al. 2012), VTT's roles can also be considered from various dimensions, such as its role in different *phases of the innovation process*, its various *networking or coordinating* roles, *geographical* dimensions, the *combining and creating* dimension of various science and technology fields, or the *education* and *competence enhancing* dimension (Table 3.1).

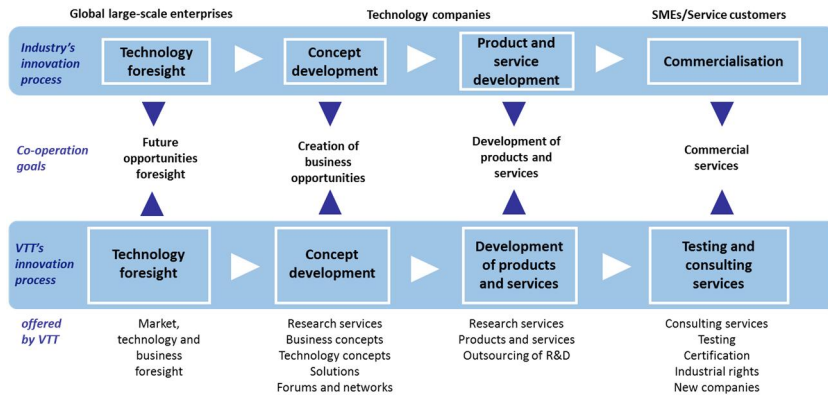
Table 3.1. Various dimensions for analysing VTT's roles.

<p>Networking dimension as networker in own and national R&D programs (SHOKs..), also other 'add value' networking services (seminars, workshops, FiDiPro, etc.)</p>	<p>Geographical dimensions by being active local, regional, national, global actor in RTI</p>	<p>Coordination dimension as coordinator of own spearhead programs, of national S&T programs, EU and global activities</p>
<p>Combination dimension by creating and networking new technology and expertise areas & related firms to create new combinations in frontier areas of S&T areas in programs and activities</p>	<p>Financial dimensions as RTI performer and networker R&D services for customers in private and public sector</p>	<p>Innovation process dimension with various roles in different stages of R&D and innovation processes (basic, applied, pilot, commercialisation)</p>
<p>Generic STI dimension as penetrator and accelerator of applications of new generic technologies to companies in various industrial fields</p>	<p>Enhancer of national STI level via most programs, many of them particularly intended to raise national scientific level</p>	<p>Future dimension as foresighter & visioner of STI a lot of potential to apply foresight more systematically in internal and external R&D and strategic activities</p>

The strategic and operational evaluation of VTT concludes that VTT's role in the innovation system has long been determined on the basis of the needs of Finnish trade and industry and large companies and that VTT has succeeded well in this role (Niinikoski et al. 2010). This will not be sufficient in the future, however. Building an internationally significant profile will continue to require cooperation with large industrial organisations, and will be achieved within the framework of global division of duties. As regards VTT's future competitiveness, this appears to pose the most important individual challenge, both to VTT's internal development and the national group steering (ibid).

Box 3.3 VTT's ideal future-oriented research, development, and innovation concept

This concept is based on the continuous interaction of innovation processes between VTT and its customers. In the early phase of new programmes, the future roadmaps of scientific and technological development and product, market, and business developments support resource allocation.



Source: VTT

VTT has been increasingly active in recent years in enhancing the foresight competencies of its researchers. One example of this has been the establishment of an internal foresight network and internal education and training of researchers in foresight methodology. The volume of VTT's foresight services nationally and internationally have increased in recent years, and VTT is well-networked in foresight activities, particularly in the EU. VTT has also participated in the methodological development of an integrated model of foresight and impact assessment supporting the Tekes research programme procedure (e.g. Hyytinen et al. 2012). After the foresight stage, VTT's service concept and reciprocal collaboration proceeds to concept development, product and service development, and finally to industrial commercialisation, for which VTT can offer testing and certification services, for example. VTT is increasingly offering services related to business concepts and business innovations. Various evaluations and impact assessment methods are used to measure the impact that VTT has on its customers. Evaluation and impact assessment has a long tradition at VTT, which started evaluating its research programmes in the mid-1980s and has run various impact assessment exercises to an increasing extent since the early 2000s.

4. Overview of impact assessment methodologies

This chapter will concentrate on describing a modern toolbox to analyse the impact of VTT. Section 4.1 gives a conventional general framework for assessing impact and effectiveness. There are numerous methods for assessing impact. When analysing impact, one can encounter an array of methodological problems. Impact is a complex phenomenon and different categories of impact have to be distinguished. A selection of methods chosen for use in this study and the authors make a number of suggestions for future VTT impact studies.

4.1 Framework for impact and effectiveness assessment

The aim of impact assessment is to indicate the additional impact of research funded from public sources as compared to a 'hands-off' alternative without public intervention (e.g. OECD 1997). Figure 4.1 presents a conventional cost-effectiveness framework in the creation, organisation, and analysis of the impact of societal programs and related key elements (e.g. EC 1997). In principal, this outline can be used to illustrate the investigation of the impact of a research organisation.

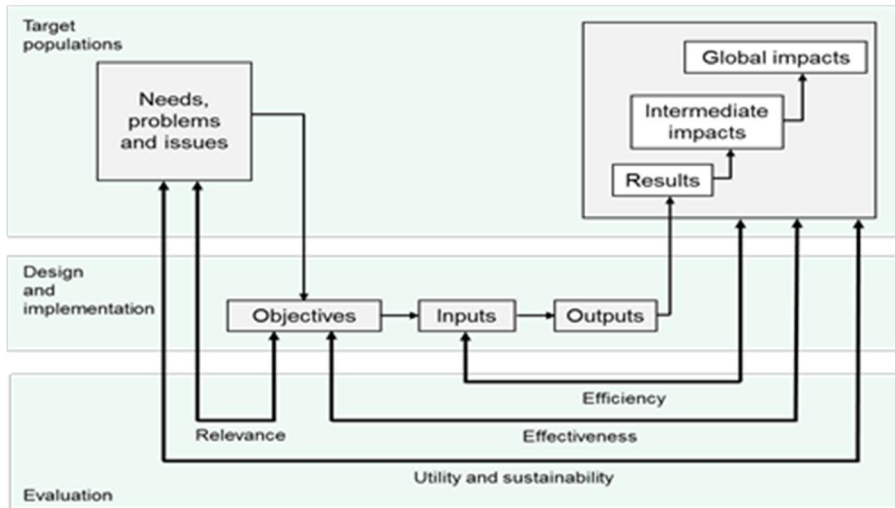


Figure 4.1. Cost-effectiveness framework of a publicly funded societal programme. Source: adapted from EC 1997.

The starting-point of public investment in research with an impact are the needs prevailing in society and the economy and the relevance of objectives addressing these needs. This is related to the issues of imperfect markets, public goods, and externalities or deficiencies in an innovation system and policy-making. Efficiency can be defined as the extent to which the desired effects (results and impact) are achieved at a reasonable cost, and effectiveness as the extent to which objectives are achieved, this being limited to objectives expressed in terms of intended results and impact (EC 1997). The EU defines impact as further and/or indirect change generated by intervention. Impact is not visible to lay-level operators and needs to be observed and analysed through specific surveys or studies (EC 1997).

The additional impact of public research funding can be economic, behavioural, and cognitive and may relate to both the inputs and outputs of research and development (Georghiou 2002). While impact assessments are increasingly used to assess the performance and effectiveness of VTT and Finnish PROs (Kuitunen and Hyytinen 2004; Lähtenmäki-Smith et al. 2006), systematic impact assessment is still in the early phase of development. The purpose of Figure 4.2 is to complete the picture of VTT's impact through four areas of additionality related to inputs, activities in R&D projects and programmes, outputs on company and industry level, and impact on the economy, society, and the wider environment.

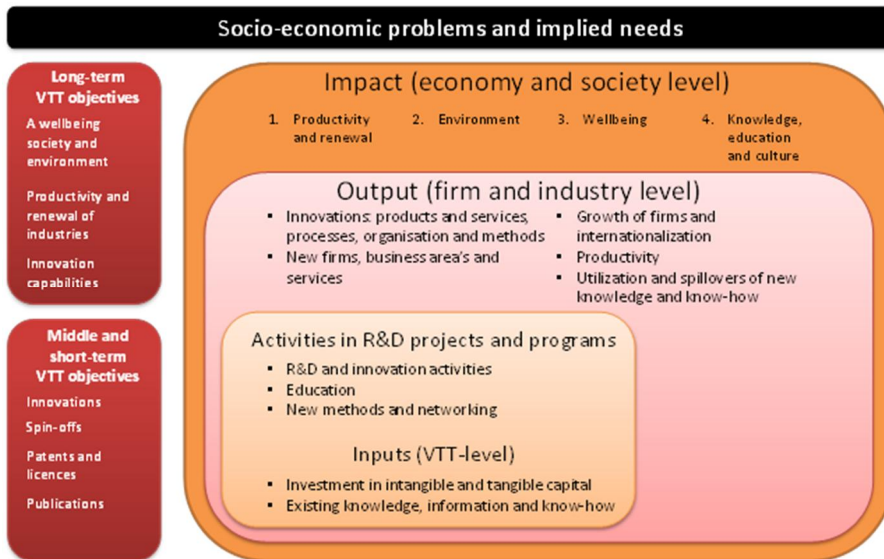


Figure 4.2. Impact model of VTT: four areas of additionality. Source: The model above goes back to the additionality theory of Georghiou (2002), and similar versions have been used by Tekes (Hyvärinen 2011) and the Academy of Finland (Lemola et al. 2008).

4.2 Multiple methods to assess impact

Evaluators use a variety of methods, each with its own advantages, disadvantages, and specialised purposes. When using a multi-faceted approach, methods should be chosen for their appropriateness to the question at hand, their cost and administrative feasibility, and whether they represent an appropriate mixture of methodological paradigms. Today, evaluators have access to an extensive and increasingly sophisticated toolkit of methodologies. Table 4.1 summarises the key methods that have been used to study R&D. These methods can be characterised based on the nature of their main results, either as quantitative or qualitative. The usefulness of methods depends, however, on the scope of the evaluation in question.

Table 4.1. Key evaluation methods for R&D activities. Source: University of Twente 2011.

Method	Mostly quantitative	Mostly qualitative
Bibliometrics	X	
Cost-Benefit Analysis	X	
Surveys	X	
Econometric Analysis	X	
Expert judgment / Peer review		X
Case Study		X
Benchmarking		X
Network Analysis		X
Technology Foresight, Roadmapping		X

Table 4.2 shows that evaluation methods can be used to support studies of different scope: (1) organisations, (2) policy, (3) programme, and (4) project. When analysing the impact of VTT, the main level of analysis is the organisation. But programme, project, and even policy levels also apply, as VTT's activities encompass a range of programmes, projects, and policy measures.

Table 4.2. Suitability of evaluation methods for R&D activities by level of analysis. Source: University of Twente 2011.

Method	Organizations	Policy	Program	Project
Bibliometrics	***	***	***	***
Cost-Benefit Analysis	***	***	***	***
Surveys	**	***	***	**
Econometric Analysis	*	***	***	**
Expert judgment / Peer review	***	***	***	***
Case Study	***	***	***	***
Benchmarking	***	***	***	***
Network Analysis	***	**	***	***
Technology Foresight, Roadmapping	*	***	***	***

***: Most Suitable, **: Suitable, *: Less suitable

The two criteria that should be used to select the right methods are the importance of the method and its plausibility. Importance refers to relevance (can it answer the main evaluation question?), comprehensiveness (can it take into account multiple objectives?), illustrativity (can it take into account risks and uncertainties?), exhaustiveness (can it take into account externalities?), and robustness (can it take into account alternative explanations?). Plausibility, for its part, refers to amicability, openness, the availability of data, the nature of data, availability of skills and knowledge, cost, time, and appropriateness. Table 4.3 summarises the strengths and weaknesses of the key evaluation methods.

Table 4.3. Strengths and weaknesses of evaluation methods. Source: University of Twente 2011.

Method	Features	Strenghts	Weaknesses
Expert Judgment / Peer Review	*Reliance on domestic and international expertise to assess quality	* Legitimacy * Cheap * Formative	* High risk of bias * Old boys club
Bibliometrics	* Use of research outputs to evaluate performance	* Cheap * Based on hard data	* Too narrow
Cost-Benefit Analysis	* Assesment of pros and cons. of past or future investments	* Persuasive	* Often contested * Not useful to evaluate basic research
Case Study	* Explores and explains the reasons behind "facts"	*Insightful	*Expensive *Risk of biased interpretations
Surveys	* Inquire profiles, performance and perception of relevant actors	* Informative	*Low response rate
Econometric Analysis	*Description and prediction of determinants and impacts via parametric estimations	* Based on hard evidence * Persuasive	* Data availability * Contested assumptions
Benchmarking	*Comparisons with referents	*Contextual	*Data availability *Plausibility of the comparisons
Network Analysis	*Connecting the dots	*Illustrating	*Persuasiveness
Technology Foresight/Assessment	*Farseeing potential scenarios	*Strategic value	*Expensive *Uncertainty

4.3 Methodological problems of impact analysis

To know if we can apply the multi-faceted approach suggested above, we need to review potential methodological problems. Previous studies aimed at analysing the impact of relationships between agents or public initiatives, as well as evaluation studies more broadly, highlight several methodological problems (based on Barge-Gil & Modrego 2011).

The first problem concerns a situation where there are no or only restricted data available. In addition, surveys for users are often characterised by response bias. A second problem is the so-called attribution problem and refers to situations where effects cannot be isolated. One solution to this is to focus on the company-level relationship with the main partner and ask how the company would have evolved without that relationship. A third problem is that different additionalities are involved and that impact is complex. Traditional studies consider only input and output additionality, although some authors have claimed that 'behavioural' or 'strategic' additionality are more important and should be taken into account (Arnold 2004). In fact, there are great disparities in recommendations on how to acknowledge success. Although impact is complex and multidimensional, many studies measure only some of its effects (Boekholt et al. 2001), and underline why it is important to distinguish between different types of impact. A fourth problem is that estimating counterfactual situations is very difficult. This issue is usually taken

handled by comparing treatment versus non-treatment or by comparing two different treatments. A fifth problem relates to the quantification of qualitative effects. Companies find it difficult to quantify the impact of knowledge-intensive services, as they find it easier to identify qualitative benefits (O'Farrell and Moffat 1995). It is important here to combine qualitative and quantitative methods to test for consistency. A sixth problem refers to the time lag between relationship and results. Most studies use 2 to 3 years, but is better to use a period of at least 5 years. There is also no single moment in time when effects can be analysed and compared. A seventh problem relates to estimating the main determinants of impact. To enable better management of an initiative and improve future results, one needs to define a holistic model to explain impact, covering both company characteristics and relationship characteristics.

4.4 Five different categories of impact

Impact is characterised by complexity and variety. As several types of VTT impact can be distinguished, it is important to be clear about the kind of impact one is referring to. As a result, we will present the general categorisation used by Barge-Gil & Modrego (2011) that is applicable to RTOs. This typology will be used in the remainder of this report. A key dimension along which different types of impact can be ordered is time and it is useful to label the nature of impact either as being short-term, mid-term, or long-term.

According to Barge-Gil & Modrego (2011), the first type of impact is *technical impact*. This refers to the immediate results of an R&D cooperation project in terms of technical output, such as innovations and patents. Scientific publications can also be included in this category.

The second category of impact is *economic impact*, referring to short- and medium-term direct effects on economic issues, such as sales, exports, production costs, profits before tax, productivity, employment, client base.

R&D activities can also have an impact on inputs. This third category of impact, often referred to in the literature as *input additionality*, captures how current changes in investments may affect future performance: machinery, information and software systems, new methods of HR management and training, internal and external R&R, acquisition of technology, patents, licences, and external non-R&D-related innovation services.

A fourth category is the *intangible impact* that affects a company's long-term competitiveness. This includes activities such as learning and staff training, teamwork and knowledge sharing, market understanding, defining and planning innovation activities, better use and selection of information and software systems, improved relationships between companies' R&D units and other units, and better information on public innovation programmes.

The fifth category of impact unites *other types of impact*. This category includes qualitative measures of impact, such as general client satisfaction, additionality offered in terms of speed, ambitiousness, and efficiency of a project. Box A.1

(Appendix 1) contains an illustration of how complex impact is and illustrates the distinction between economic impact and social impact and between short-term and long-term impact.

Assessing the overall impact of VTT requires an analysis of different categories of impact. Although such a holistic approach does not come within the scope of this study, we will conclude this chapter by clarifying which kind of methods will be used to analyse which kind of impact. In addition, we will make various suggestions on which areas of impact should be studied in future VTT impact studies. The following three chapters will assess the different roles that VTT has and carry out pilot studies on the selected methods for pinpointing future good practice for VTT impact studies.

4.5 Towards future good practice in VTT impact studies

VTT has a long tradition of assessing its impact on the economy and society. The latest external VTT impact analysis appeared in 2010 (Niinikoski et al. 2010), while the latest internal evaluation dates from 2006 (Lähteenmäki-Smith et al. 2006). Table 4.4 summarises the methodologies used in these most recent impact studies. In addition, the table contains key methodological information on the impact study presented in this report. By mapping the objectives of our impact study and the characteristics of the different evaluation methods, we suggest using a multi-faceted approach as a benchmark of best practice. The final section of the table highlights priorities related to future VTT impact studies.

In conclusion, the authors recommend launching a new series of VTT impact studies to analyse the different aspects of VTT's impact on the Finnish economy and society. These studies would benefit from better data and use of the latest evaluation methods. The table below makes suggestions for useful future research that could help both policy-makers and VTT management to fine-tune strategy and operations. Ideally, impact studies should use complementary methods to test the robustness of their results. The remainder of this report presents quantitative and qualitative evidence on the roles of VTT.

Table 4.4. Towards a multi-faceted approach for analysing the impact and outputs of VTT. Source: VTT Innovation Studies.

Impact study	Key questions addressed	Used methods
Impact studies ordered by the Ministry since 2000		
Niinikoski et al. (2010)	(1) What is VTT's role in the innovation system? (2) What is VTT's position as part of the Ministry of Employment and the Economy? (3) How well do VTT's operations function?	*Individual and group interviews *Internet based survey *Benchmarking with RTO's abroad
Artimo et al. (2004)	What are the structural and operational challenges for VTT?	*Interviews (n=57)
Internal impact studies of VTT since 2000		
Anttila & Niskanen (2001)	VTT's impacts	*Interviews
Kutinlahti & Hyytinen (2002)	Societal impact of VTT and its role in the national innovation system	*Interviews (n=30)
Oksanen (2003)	What is the regional impact of VTT? With focus on VTT networking, accessibility of services and image	*Firm-level survey (n=445) *Stakeholder interviews (n=29)
Kuitunen and Hyytinen (2004)	Handbook on impact and effectiveness evaluation of public RTOs	*Interviews
Lahteenmäki-Smith et al. (2006)	What are the methods and indicators needed to analyse impact of VTT and 4 other selected RTO's?	*Interviews with personnel (n=31) and key stakeholders (n=48)
Current study (Loikkanen et al. 2013)	(1) What are the value added roles VTT plays (2) How important VTT has been for Finnish innovations	*Descriptives of innovation-level survey data (Sfinno database, n=1077) *Bibliometrics *Case-studies
Suggestions for future impact assessment studies		
VTT impact series no. 1 (potential future study)	(1) What is the effect of VTT on their clients? (1.1) Value-added wise (1.2) Regional wise	*Econometric study based on a database that contains info on the full population of VTT clients
VTT impact series no. 2 (potential future study)	(2) Where do VTT researchers come from and where do they go?	*Network analysis based on HR-data, employee data, FLEED data
Vtt impact series no. 3 (potential future study)	(3) How does VTT perform compared to its peers abroad? (3.1) When it comes to creation of spin-offs (3.2) When it comes to innovation outputs and inputs (3.3) When it comes to combining technological capabilities with other capabilities	*Benchmarking *Case-studies *Interviews *Econometrics

5. Quality, commercialisation, and internationalisation of VTT's research activities

Chapter 5 discusses three important aspects of VTT's research and innovation services: the scientific quality of its research according to bibliometric data; the main channels and various aspects of the commercialisation of VTT's research; and the internationalisation of VTT's research services and activities. The high scientific quality of VTT's research services is an important credibility criterion both for VTT's clients and for the Ministry of Employment and the Economy, because the aim of basic government funding to VTT, in addition to funding strategic long-term research, is also to develop high-level scientific competences for high-quality research services.

Section 5.1 analyses bibliometric evidence related to the quality of VTT's research. Various ways to commercialise research results in the form of contract research or IPR such as patents or spin-off companies are among the key strategies applied by RTOS such as, and the role of Section 5.2 is to consider the channels of commercialisation of research results at VTT. RTOs are part of the global scientific community and are affected by and integrated into global scientific and technological development. Section 5.3 provides an overview of the existing state-of-the-art and forms of VTT's internationalisation and related challenges in the future.

5.1 Bibliometric evidence related to their quality of VTT's research

In general, bibliometric studies on the research performance of RTOs are rare or non-existent (for an exception, see Solberg et al. 2012). Universities and other public research organisations are commonly seen as the primary performers of scientific publishing, whereas RTOs are perceived as performers of industrial innovation and development rather than publishers (cf. Arnold et al. 2010). However, the recent efforts of the Finnish Ministry of Education and Culture are attempting to fill this gap in the case of Finland. The reports prepared by the Finnish Citation Index Working Group assigned by the Ministry focus on the publication

and citation output of VTT in comparison with other Finnish research organisations during the 1990s and 2000s (Ministry of Education and Culture 2011a; 2011b; 2012).

According to the results of the Finnish Citation Index Working Group, the quality of research carried out by VTT is of a high calibre compared to the most productive public research organisations in Finland. The comparison addressed both Finnish universities and public research organisations. During 2006–2008, VTT's field-normalized relative citation index was 1.17, the fourth-highest figure amongst Finnish research organisations (Figure 5.1). VTT's Top-10 index on the proportion of scientific publications positioned in the top 10% of the world's most-cited publications was 1.2, the second-highest figure in the comparison (Ministry of Education and Culture 2012, 18).

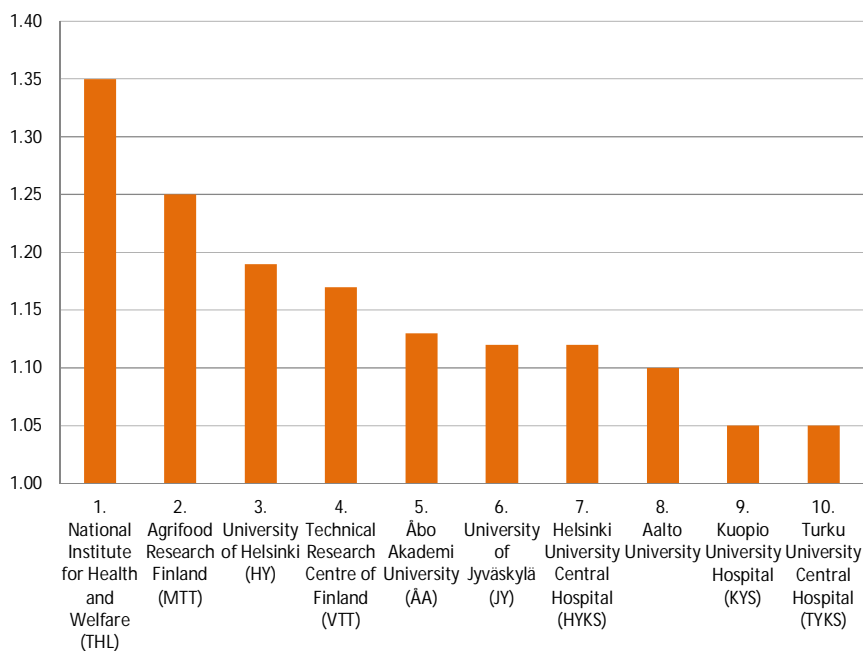


Figure 5.1. Top 10 Finnish research performers ranked by the citation index for 2006–2008 (based on Thomson Reuters Web of Knowledge data, field-normalization in use). Source: Ministry of Education and Culture 2012.

VTT's share of the total number of scientific publications in Finland only amounted to 2.5% in 2006–2009, which is not on a par with most Finnish research organisation, especially if the number of research personnel at VTT (1,831 in 2010) is compared to that of all Finnish universities (29,952 in 2010) (Figure 5.2). These figures imply that highly-cited and acknowledged research is achieved by VTT with a relatively small publication output. The most important research field at VTT is

the natural sciences in terms of publication quantity, which makes no difference in comparison to public research in general. It is worth noting that VTT's share of Finnish engineering publications was 7.7% in 2006–2009 and was surpassed by Aalto University (26.2%), Tampere University of Technology (11.1%), and the University of Oulu (8.1%) during the same time period. When it comes to the Finnish publication landscape, VTT's role today is significantly different from what it used to be in the early 1990s, when VTT's share of Finnish engineering publications stood at 15.4%. (Ministry of Education and Culture 2012, 42.)

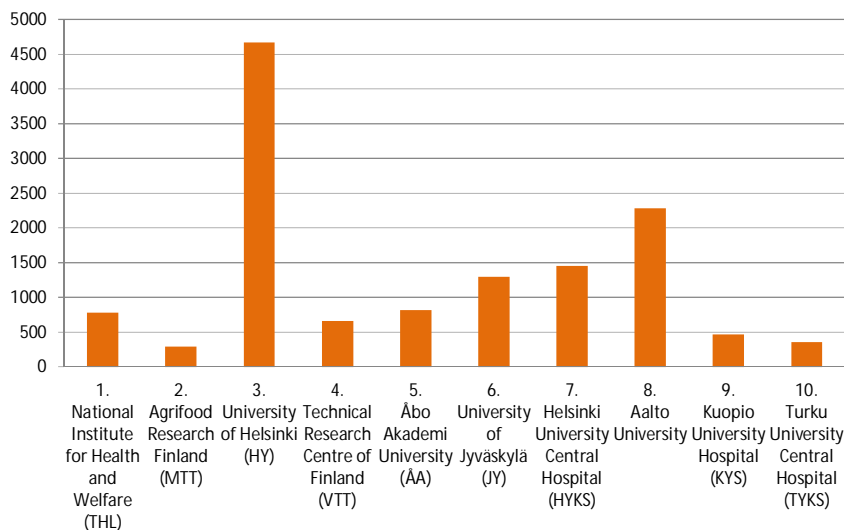


Figure 5.2. Number of publications of Finland's top 10 research organisations ranked by the citation index for 2006–2009 (based on Thomson Reuters Web of Knowledge data, international fractionalized count). Source: Ministry of Education and Culture 2012.

The work of the Finnish Citation Index Working Group also looked at how international VTT's publication activities are and how international collaboration affects the citation index. In 2003–2008, the total number of publications contributed by VTT totalled 1,902. If we fractionalize this figure in accordance with the organisational background of domestic authors, the number is significantly lower, 1,304. If we fractionalize the figure to take account of foreign authors, the number is 969. This implies that the majority of VTT's publications are the result of international and national collaboration, which is similar to the performance of other Finnish research actors (Ministry of Education and Culture 2011a, 24).

The share of joint publications co-authored with international partners has steadily increased, from 25% in 1990–1993 to 42% in 2006–2009 (Table 5.1). In this respect, VTT has followed the common trend taking place in the internationalisation of Finnish universities and public research organisations (Ministry of Education and Culture 2011b, 115).

Table 5.1. Proportion of international joint publications at VTT in 1990–2009. Source: Ministry of Education and Culture 2011b.

	1990-1993	1994-1997	1998-2001	2002-2005	2006-2009
Share of international joint publications	25 %	29 %	37 %	39 %	42 %

In comparison to other European RTOs, VTT’s publication output has followed a similar growth trend to that seen at SINTEF (Norway) and Fraunhofer (Germany) and is approaching the total publication volume achieved by TNO (The Netherlands), which is a larger RTO than VTT in terms of researcher personnel (Figure 5.3).

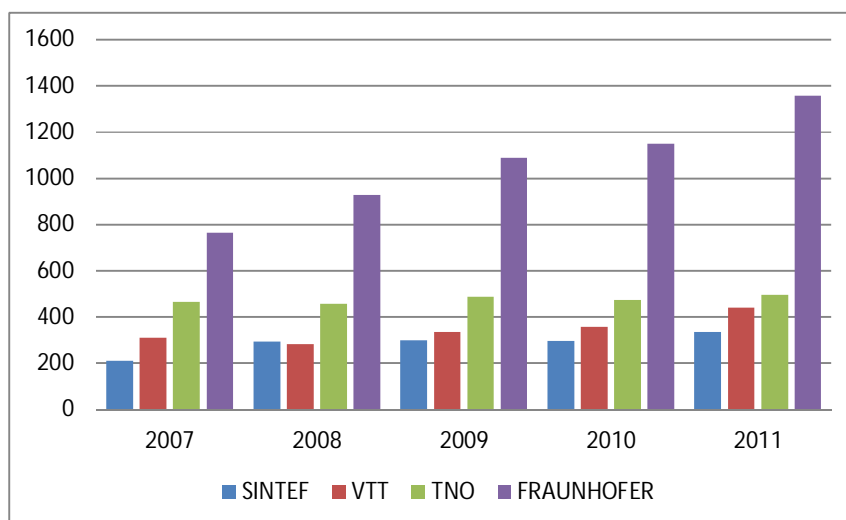


Figure 5.3. The total number of publications of four European RTOs (SINTEF, VTT, TNO, and Franhofer) in 2007–2011. Source: Web of Science, authors’ calculations.

While bibliometric indicators should be assessed carefully, the figures above indicate that VTT produces original research that fulfils the quality criteria of major scientific journals and is of interest to other researchers in the 2000s. Publications are often internationally co-authored today, which has a positive impact on the worldwide visibility of research results. Bibliometric indicator data also imply that VTT plays a role not only in applied research directed towards practical aims and objectives but also in generating new knowledge directed towards broader scientific audiences. In research and innovation policy, the latter role is usually reserved for universities since they are seen as the main performers of basic research.

The bibliometric evidence gives food for thought when addressing the role of VTT in the Finnish innovation system and the prevailing division between basic and applied research. This division may result in far-reaching policy consequences, as the recent thoughts of the Research and Innovation Council of Finland appear to imply. The Research and Innovation Policy Guidelines for 2011–2015 underline the fact that Finnish public research organisations play a key role in applied research that is multidisciplinary in character (Research and Innovation Council 2010, 36). Recently, the expert group of sectoral research reform assigned by the Council suggests that all basic research should be transferred to Finland's universities from public research organisations such as VTT (Lankinen et al. 2012, 37).

The division between basic and applied research is also well-established in R&D statistics worldwide, largely owing to the long-standing efforts of OECD. In this respect, the OECD's Frascati manual represents an important document as it defines guidelines for collecting R&D statistics (OECD 2002). The definitions provided by the Frascati manual represent two research types that are mutually exclusive, result in different outcomes, and are performed by different actors. These definitions have remained essentially unchanged since 1963 and have become well-established in the research and innovation policy of OECD countries during the course of 50 years (Godin 2000).

The development of modern research fields, such as biotechnology and molecular biology, has seriously challenged the one-dimensional dichotomy of basic and applied research in research and innovation policy. Research on interferons in molecular biology, for example, has resulted in both fundamental knowledge on recombinant DNA and high-profit applications (Stokes 1997, 14). Research can simultaneously be interested in improving the fundamental understanding of a phenomenon and how the new knowledge produced can be utilised. This expanded motivation of research is poorly captured by both the OECD's classification and debate on research and innovation policy. However, the bibliometric figures indicate that an RTO such as VTT can contribute to basic research even though its main role is in applied research and industrial applications. This is a fruitful starting-point for strengthening collaboration between Finnish universities and VTT.

5.2 The commercialisation of VTT's research

5.2.1 Introduction

Knowledge and research generated by public research organisations is diffused through a variety of channels – (1) the mobility of scientific staff, (2) scientific publications and conferences, (3) contract research with industry and (4) the licensing of inventions. However, much of the policy focus in OECD countries has focused on promoting knowledge transfer via a dual model of commercialisation. This model is characterised by supply push forces, whereby public research institutes and universities transfer academic inventions via the sale, transfer, or licensing of intellectual property, often on an exclusive basis, to existing companies or new

ventures (academic spin-offs). The converse of the supply push model is a demand pull model based on contract research or collaborative R&D, whereby public research institutes are solicited by industrial actors to find solutions to production and innovation problems (OECD 2012).

These two previously distinct linear models of commercialisation are becoming increasingly integrated, with research and innovation relying on greater openness and collaboration, both upstream on the research side and downstream on the commercialisation path. Openness in science (open science) increases the number of channels available for transferring and diffusing research results, while open innovation in companies creates a division of labour in the sourcing of ideas and their exploitation. This has given rise to intermediaries that broker commercialisation activities, notably intellectual property services. Institutional capabilities are a crucial condition for commercialising public research. Many OECD countries have therefore set up technology transfer and licence offices at universities and public research institutes. The productivity of most of these offices is still measured by numbers of patents and licences. Even if these have been increasing in many OECD countries, they are considered traditional measures of technology transfer, as they represent a very small share of the knowledge that is transferred from public research institutes and universities. As a result, OECD countries have begun to complement institutional and legal support for technology transfer and commercialisation with support for entrepreneurial channels for commercialising knowledge (OECD 2012). This chapter will discuss the commercialisation of VTT's research results based on traditional intellectual property protection measures, such as patents, copyrights, and trade secrets. Attention will also be given to VTT's entrepreneurial and spin-off activities, as well as VTT's client base and its contract research and cooperative R&D.

5.2.2 VTT's knowledge transfer in the light of traditional technology transfer indicators: patents and licences

VTT's primary purpose is to support innovation activities of its customers. The technology transfer activities of RTOs via commercialisations are typically measured by patents and licences. The direct benefit of owning patents for an RTO is that they can generate financial income, which can be reinvested in technology transfer activities. Structurally, however, RTOs build up strategic patent portfolios to signal the innovativeness and quality of the R&D work that they undertake. The signalling role played by patent activities is important, as it can allow the expansion of networks and the generation of new business. To reach global technological excellence, VTT is continuously striving towards a strong IPR portfolio. With a portfolio of 1,239 patents spread over 342 patent families, VTT is currently³ one of

³ Situation as of 23 January 2013. Out of a total portfolio of 1,239 patents and applications, 748 were pending and 491 were granted.

the most active Finnish players in patenting technologies. The dynamics of VTT's patent portfolio are mainly driven by VTT's strategy of focusing on a set of core technologies supported by enabling technologies.

While focusing on core technologies, VTT promotes invention disclosures throughout its organisation. Inventions are first identified and invention disclosures submitted to the central business development unit. Each disclosure is evaluated and, after a positive cost-benefit analysis, the optimal protection and commercialisation strategy is agreed. Only the best invention disclosures go forward to a patent application. In summary, the journey to being granted a patent is long and consists of several internal and external selection stages.

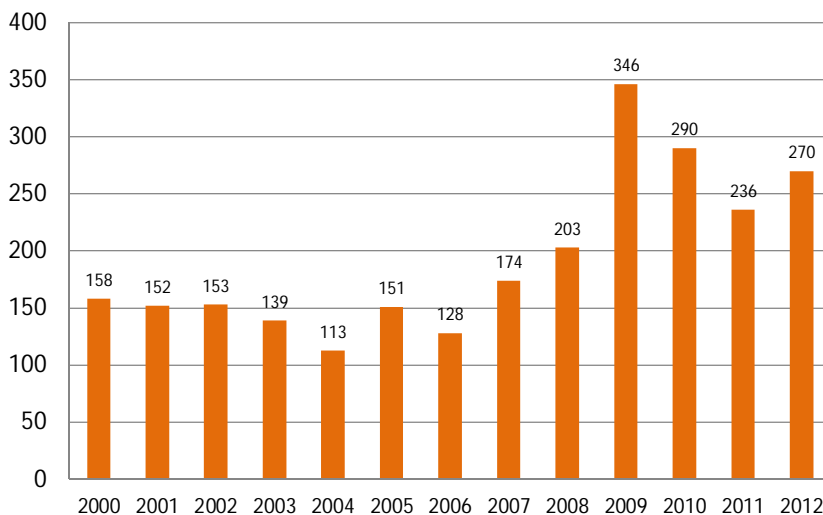


Figure 5.4. The annual evolution of the number of invention disclosures at VTT. Source: VTT's calculations.

Figure 5.4 shows that in 2012 VTT received 270 invention disclosures. Developments since 2000 indicate a relative stable amount of invention disclosures until 2006, after which they started rising and stabilised at roughly twice the previous level. As a consequence of a change in internal performance measures in 2008, the number of invention disclosures increased and VTT was able to become more active in areas where invention activities were low previously. As the number of invention disclosures became a key internal performance criterion, the threshold for submitting inventions became lower and the pool of invention disclosures contained more inventions with low potential.

Figure 5.5 shows the annual evolution of VTT's priority patent applications in Finland and abroad, and Figure 5.6 compares priority patent applications to invention disclosures. The evolution of patent applications initially follows the same trend as invention disclosures, with a jump in applications in 2009. During the last

few years however, patent applications have returned to the pre-2009 level, unlike invention disclosures.

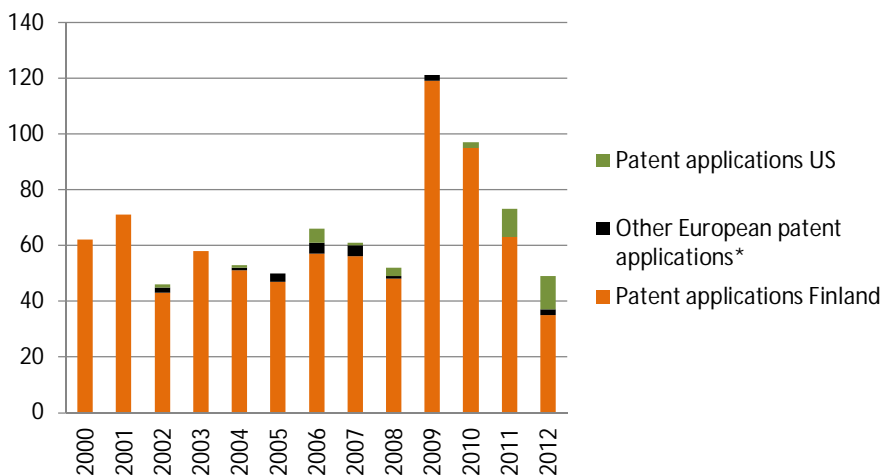


Figure 5.5. Annual evolution of the number of VTT's priority patent applications. Source: VTT. In this figure patent applications refer to priority patent applications.

Figure 5.6 shows that more invention disclosures, in combination with only a slightly increased VTT budget for patenting, resulted in only a limited number of invention disclosures making it to the patent application stage.

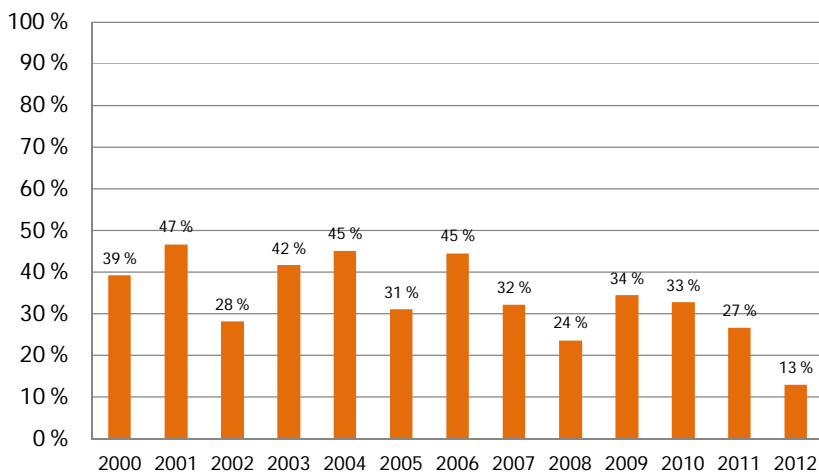


Figure 5.6. Evolution of proportion of VTT's invention disclosures that lead to a patent application in Finland. Source: VTT. Patent applications here refer to priority patent applications.

In addition, VTT's internal selection process has become stricter, as patent applications can typically be costly and, by definition, many patents turn out to cost more than what they generate financially, and costs increase over time. Patent value distributions are known to be highly skewed, as many patents generate no or very little income and only few patents turn out to be very successful. In brief, a rise in invention disclosures over the mid-term did not translate into a rise in patent applications due to the high internal quality thresholds used and VTT's budget limitations. In addition, there seems to be considerable differences between different technology areas.

VTT's annual IPR income has been increasing and amounted to €2.1 million in 2012. Although the amount roughly doubled during the last five years, it is still limited.

5.2.3 The role of VTT in entrepreneurship creating spin-offs

In addition to institutional and legal support for technology transfer and commercialisation, VTT also works with entrepreneurial channels for commercialising knowledge via spinning off start-ups and complementing its technological expertise with complementary knowledge from its network of incubators, accelerators, mentors, trainers, and venture and angel capital players. This section summarises VTT's spin-off activities and describes VTT's new approach to infusing its research activities with a more entrepreneurial spirit.

To stimulate innovation, VTT started to focus more on technology transfer via entrepreneurial activities and founded a subsidiary, VTT Ventures Ltd., which seeks talented and experienced entrepreneurs to champion the commercialization of its technology via spin-off companies. VTT Ventures has essentially three roles: (1) developing spin-off companies with international growth potential based on VTT technology, (2) making pre-seed and seed phase investments, and (3) transferring technology to the spin-off companies in portfolio. VTT Ventures provides entrepreneurs with professional business development support, together with its public and private innovation partners to facilitate the spin-off process, from business planning to funding. VTT Ventures has invested in 23 companies, which raised an overall capital of €15 million. VTT Ventures' current spin-off portfolio includes 20 companies in the start-up phase. VTT Ventures co-invests in its spin-offs with private investors. VTT cooperates with venture capital players to make investments ranging in size from €100,000 to €1 million. An exit is expected between 5 to 7 years from entry.

Figure 5.7 illustrates VTT's innovation process from when an idea is generated to the point a technology-based start-up is sold. The first stage of the process consists of screening ideas from different areas of activities at VTT. At the end of this first stage, ideas are selected and an optimal commercialisation strategy developed. If the optimal strategy turns out to be a spin-off, the case is transferred to VTT Ventures. The second stage of the innovation process takes place at VTT Ventures and consists of the evaluation of the spin-off project. If this evaluation is successful, an investment is made and an exit target established.

To stimulate its innovation process, VTT has a range of commercialisation projects aimed at enhancing the commercial potential of research results, inventions, and other concepts. These projects are essentially business development projects and can either be self-financed or jointly funded. VTT has three categories of commercialisation projects: (1) Tekes TUTL (New knowledge and business generated from research ideas) projects, (2) VTT BizFund projects, and (3) other commercialisation projects.

Tekes TUTL projects only finance research that produces new knowledge and expertise that is relevant to the utilisation of a research idea. In addition, preparation work for commercialising research results must take place parallel to the research in question. As a result, the budget for this stage always plays a very significant role (>30%). Potential paths for utilising research results are examined and the most promising path and method is chosen. The main alternatives are starting-up a new business or utilising a new business in an existing company.

The innovation process

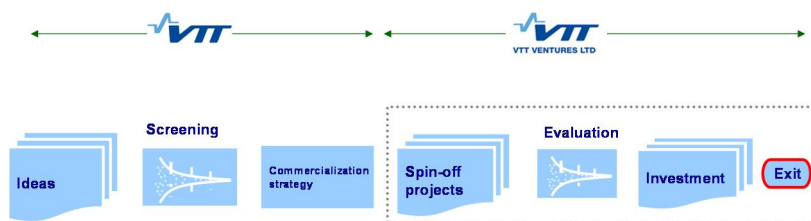


Figure 5.7. The steps in VTT’s internal innovation process. Source: VTT Ventures.

VTT Bizfund is a funding instrument for accelerating the commercialisation of research results in VTT’s key research and innovation areas. Typically, projects should not last longer than 4 months and project budgets are normally in the €20–50,000 range. Actions that can be funded range from market studies through IPR studies to assessments and demonstrations.

5.2.4 Contract research and collaborative R&D

The most important channel for commercialising VTT research is contract research and development. In 2012, these activities represented roughly €80 million or 30% of VTT’s turnover. The vast majority (80% to 90%) of contract research is done for Finnish companies. In the case of contract research, recurrent income is uncertain. VTT’s contract research involves the treatment of IPRs, which represent another channel through which VTT’s research can be commercialised (see section 6.2). The IPRs used in contract research may lead to recurrent licencing income. VTT has certain core technologies for which the ownership of patents is

crucial. The timing of an IPR contract is important and IPRs depend on industry. Patents are important for commercialising technological products, but they also signal how active VTT is as an innovator for potential national and international clients. This section describes the composition and evolution of VTT's client base and summarises the key results of VTT's annual client survey.

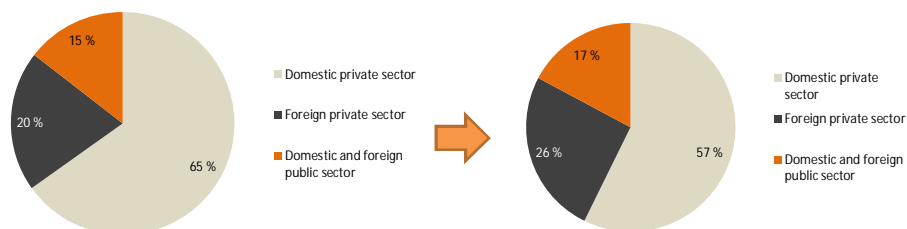


Figure 5.8. Shares of VTT's client types based on number of clients: comparison between 2010 (on the left) and 2012 (on the right). Source: VTT.

VTT has a large client base of roughly 1,500 clients. The vast majority of clients are Finnish companies, but for contract research there is a clear trend towards more foreign clients. In 2012, VTT had 1,510 customers, of which 865 were Finnish companies, 385 were foreign companies, and 260 were public organisations in Finland and abroad. Acquiring foreign clients for contract research is the most obvious way to expand VTT's activities due to the small size of the Finnish market. To capture market share, RTOs have opened sales offices in key overseas markets and more recently have been expanding their R&D activities in foreign locations. This helps them acquire new clients and allows them to absorb knowledge from important emerging clusters. Embracing internationalisation offers many opportunities for VTT. This issue is not always straightforward for a public research organisation, however.

Another way for VTT to grow is to expand domestically by supporting its Finnish client base with larger contracts and or to expand its Finnish client base with more small and medium-sized firms (SMEs). The latter option has recently been seen as a particular opportunity. Roughly half of VTT's national and international private client database in 2012 were SMEs (640 out of 1,250). Typically about 50% of these are involved in contract research with VTT (commercial activities), while roughly 80% are involved in jointly funded projects (non-commercial activities). The term SME is characterised by a lot of heterogeneity, however, not least because it covers both very small companies of 10 employees up to businesses employing 249 people. These companies can also differ significantly in terms of their innovative activities and performance.

In addition to turning to VTT for R&D assistance, companies also hire R&D personnel themselves to work on their core competences. As a result, R&D is often contracted out if it relates to complementarities. In that sense, it is more challenging to contribute to the strategic core of SMEs. Rather than absolute numbers,

therefore, it is the share of VTT contract research in the turnover and R&D investments of client companies that matters the most. Partly related to the size of clients is the fact that there is a minimal contract size threshold for an RTO, because of the high fixed costs (partly due to overheads) involved in attracting new clients.

If VTT wants to strengthen and expand its client base, it must listen closely to whether its clients are satisfied. This is why VTT runs a recurring client survey. The purpose of the survey is twofold: (1) To find out to what extent cooperation with VTT produces benefits for clients, and (2) to find out how satisfied clients are with VTT's operations. In the latest available survey, a sample of 150 clients was interviewed. The results for international and Finnish clients have been analysed separately. According to the 2012 VTT customer survey by Taloustutkimus Oy (VTT 2012), VTT customers rated VTT activities highly in general as well as the impact that cooperation with VTT generates. The most frequent benefit mentioned was increased knowledge and competence. More than half of Finnish customers feel that cooperation with VTT also leads to the following benefits: R&D processes have been fostered or improved, new or improved products, services, or production processes have been created, new business opportunities have been opened up, and new networking partnerships have been generated. Customers expect more active contacts, better communications after projects have been completed, and a clearer presentation of VTT's total offering. The commercial utilisation of results remains good. Finnish customers appreciate VTT most for being honest, unbiased, and reliable. The weakest grades were given for customer and need orientation and pioneering activity. International customers appreciate VTT's cooperation capabilities and rate the quality of VTT's activities as very good internationally.

In summary, VTT's research is commercialised via a number of different channels. The most important channel runs via R&D contract research and other research for clients. VTT has a large client base that is increasingly focusing on international clients. A big challenge facing VTT is to make it viable to cooperate with small players that need to source technological know-how. Client satisfaction is crucial and VTT is aiming to further invest in improving its relationship with current and new clients. A second commercialisation channel runs via the creation of technology based spin-offs. Since the recent foundation of VTT Ventures, VTT has already invested in more than 20 spin-offs. It is important that entrepreneurs and risk financing can be matched with the technological opportunities arising in VTT, as fusing different areas of know-how maximises the potential success of commercialisation and start-ups. Last but not least, a third channel for commercialising VTT research runs via its patents and licences activities. Typically, these activities are highly skewed and only a few generate income. A well-balanced and hand-picked IPR portfolio is of strategic importance to VTT, however, as it is to all ambitious technology players around the globe.

5.3 VTT's internationalisation challenge

Internationalisation has a variety of impact on innovation systems, innovation policies, and policy thinking (e.g. Edler and Flanagan 2011). While science and technology are by nature global public goods, VTT and other Finnish PROs, as well foreign RTOs similar to VTT, are part of the global scientific community and affected by and integrated into global scientific development. The global landscape is continuously changing. Transnational corporations are driving global development, and globalisation is led by the ICT and knowledge-based paradigm. Large emerging economies are also changing the dynamics of the global economic and innovation geography. The global dynamics of innovation are changing due to the opening up of global innovation operations (Deschryvere and Ali-Yrkkö 2013). All of these changes not only pose new challenges, but also give new opportunities for PROs.

Table 5.2. VTT's position in the European R&D&I landscape.

	Overall ranking	Networking ranking*
2007	39	32
2008	10	5
2009	9	4
2010	16	7
2011	12	6

Source: European research ranking. *The networking ranking is a proxy for reputation. The overall European research ranking is based on the following indicators: (1) Funding and project participation performance; (2) Networking activity and alliances; and (3) Diversity of research areas.

VTT has various international activities and is both affected by international developments and may itself also have various opportunities internationally. Research collaboration in EU programmes represent the largest part of VTT's international activities, and VTT accounted for the largest share of Finnish research organisations in the EU's framework programmes in 2011. Table 5.2 shows that VTT has a very good European ranking (ranked 12th in 2011) in attracting European project funding and that it has a good networking activity and reputation (ranked 6th in 2011). The volume of VTT's European public project financing amounted to €64.2 million in 2012, of which €47.4 million could be attributed to EU projects, €12.6 million came from European Economic Areas (ERA) projects, and €4.3 million came from other European collaboration projects. Figure 5.9 shows that VTT's operating income from European projects has been increasing steadily, from roughly €20 million in 2007 to €50 million in 2012. VTT's revenue from overseas amounted to 18% of all revenue in 2011, of which 11% was accounted for by EU programme project funding. VTT has increased its international income substantially since the beginning of the last decade and the volume of foreign company funding at VTT has been the highest of any Finnish PRO (Loikkanen et al. 2010).

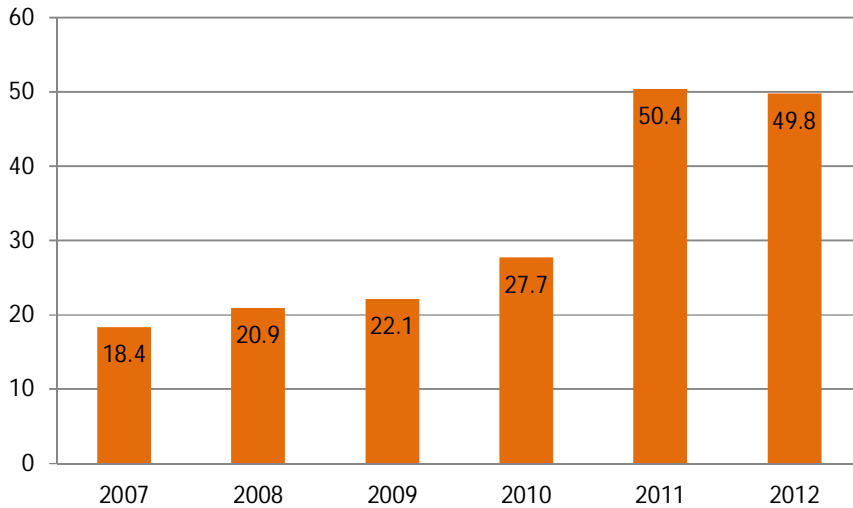


Figure 5.9. Evolution of VTT's operating income from European projects (in € millions). Source: VTT.

Wide-ranging exchange of scientists and experts is one of the most important channels for the inflow of knowledge from foreign countries and excellence centres to VTT, as well as from VTT to various positions providing high-level scientific expertise. VTT created a visiting research professor programme in 2008, since when there have been 10 foreign visiting professors at VTT. Dozens of VTT experts hold positions of trust overseas, especially in EU expert groups, but also in international scientific organisations and associations. VTT does not collect data on this areas, but estimates that there are a few dozen experts actively involved in expert duties in scientific organisations (Loikkanen et al. 2010). VTT's expertise is utilised by the European Union in developing and revising directives, for example, in areas such as vehicle emissions standards.

Box 5.1 EARTO

The mission of the European Association of Research and Technology Organisations (EARTO) is: (1) to promote and defend the interests of RTOs in Europe by reinforcing their profile and position as key players in the minds of EU decision-makers and by seeking to ensure that European R&D and innovation programmes are best attuned to their interests, and (2) to provide added-value services to EARTO members to help them to improve their operational practices and business performance as well as to provide them with information and advice to help them make the best use of European R&D and innovation programme funding opportunities. The Association represents the interests of about 350 RTOs from across the European Union and 'FP-associated' countries. VTT has been a member of EARTO since 2000 and, like other RTOs, benefits from membership as a channel to influence European innovation policy-making. The strategy and action plan of Key Enabling Technologies (KETs) is based on an EARTO initiative launched during the presidency of VTT in EARTO, for example.

VTT's impact with respect to international activities does not occur only through direct international scientific and technological collaboration but, also very importantly, via utilisation of VTT's scientific and technological knowledge in national projects aimed at strengthening the competitiveness of Finnish companies in international markets, for example. We do not, however, have any comprehensive estimations of this impact, but it could be explored in more detail separately by interviews or customer survey investigations.

In conclusion, VTT has various 'inflow' and 'outflow' impact with respect to its international activities, and is further developing its existing forms of international activities and introducing new ones. One example of relatively new collaboration is Kemira Corporation's and VTT's joint R&D centre in São Paulo, Brazil focused primarily on water chemistry and biomass utilisation applications. Another example is the Joint Institute for Innovation Policy (JIIP), a joint venture between four well-respected RTOs – TNO (The Netherlands), VTT, Joanneum Research (Austria), and Tecnalia (Spain) – which provides intelligence to support policy-making with a focus on research and innovation policy for the EU and other customers. The critical issue in internalisation is what different outflows from Finland and inflows from abroad represents in terms of money, knowledge 'spill-overs', and other relevant measurable or non-measurable units. As in the case of other PROs in Finland, a more sophisticated rationale for the public funding of international activities by VTT can only really be defined when more precise data on these outflows and inflows is available.

6. The role of VTT in nurturing innovations: analysis of the SFINNO database

6.1 A closer look at the characteristics of Finnish innovations

VTT played a consistently significant role in Finnish innovations in recent decades by providing basic research services and applied research services, as well as services for product and service development. VTT has been directly involved in more than one third of Finnish innovations, either as a collaboration partner in the R&D of Finnish and foreign companies or – and increasingly so – as a partner for commercialising its in-house R&D. This allows VTT to have an impact on the renewal of Finnish industry and create new companies and new business growth.

In this section, we will examine VTT's role in Finnish innovations, based on results obtained from the SFINNO database (see Box 6.1 below).

The SFINNO database offers a good basis for assessing the importance of VTT for Finnish innovations, as well as the characteristics of these innovations. In particular, our results are based on – and therefore limited to – the survey responses of innovators in Finland. Generally speaking, these survey answers reveal that VTT played a role in 36% of the innovations commercialised in Finland between 1985 and 2009 (Figure 6.1).

Figure 6.1 also shows that VTT plays a major role in Finnish innovations by injecting R&D capacity in established companies. In addition to its role as a R&D collaboration partner for many companies, VTT also commercialises its in-house R&D via its own spin-off activities via VTT Ventures Ltd. (see box below).

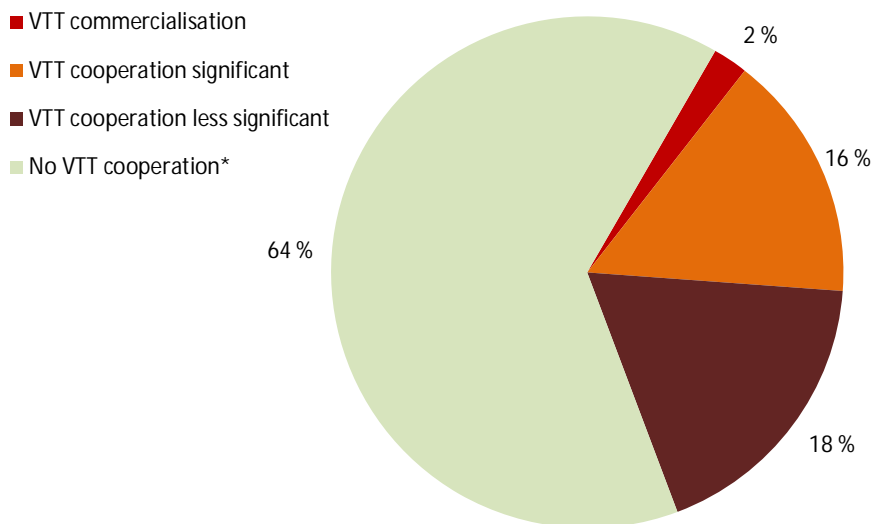


Figure 6.1. Share of innovations for which VTT played a role in their R&D or commercialisation. Source: VTT SFINNO™ Database, 1985–2009, N=1077. Note: The category 'No VTT cooperation' includes innovations for which VTT was reported to have no significance (n=473) and innovations for which no information on VTT cooperation was reported (n=217).

The importance of R&D cooperation with VTT naturally varied over the innovations considered and was significant to very significant in 16% of cases and less substantial in 18% of cases. It is important to underline that in 2% of Finnish innovations VTT played a creative role by commercialising its own R&D results in the form of its spin-off companies. Although the overall share of VTT commercialisations may seem small, turning to the dynamics in Figure 2 reveals a more encouraging message.

Box 6.1 The SFINNO database

The SFINNO database contains data on significant innovations mainly related to products and processes developed by Finnish companies. It provides a unique view for understanding broader economic and industrial processes, such as the renewal and development affecting different sectors. SFINNO currently encompasses almost 5,000 individual innovations commercialised between 1945 and 2009. This makes it one of the most comprehensive databases of its kind. The basic data has been collected by identifying innovations from 15 industrial and professional journals that cover a fairly wide range of industries. In addition, the identification process includes surveying the annual reports of Finland's 20 largest companies as well as expert interviews. Innovations are identified by VTT's research team.

An 'innovation' is defined as "an invention that has been commercialized by a firm or equivalent" (OECD 2005). Furthermore, recorded innovations must fulfill the criteria of being: 1) commercialised; 2) novel, or a significant improvement in a company's existing product range; 3) developed at least partially in-house by the company commercializing it; and 4) developed and commercialised by a Finnish company or a foreign affiliate domiciled in Finland.

The database is built from two blocks: a) basic data and b) questionnaire data:

Basic data

An innovation's basic data comprises the innovation's name, description, and year of commercialisation, as well as information on the company responsible for its development. The company's information is supplemented with information from secondary sources, such as business register and patent data.

Questionnaire data

Questionnaires are sent to innovators to discover more detailed information on innovation development. This supplementary data includes details such as the milestones of an innovation's development, collaboration patterns, R&D funding, and the commercial significance of an innovation. Questionnaire data has been gathered on commercialised innovations since 1985. It is this part of the data that allows us to assess most of VTT's role in the innovation development of Finnish companies.

Alternative available innovation data often report general innovation activity in companies, but not the detailed information on individual innovations. In addition to the above, further strengths of an innovation-based approach include being able to monitor diverging types of innovations, a wide variety of industries and sectors, and including even very small companies (i.e. firms employing less than nine people).

A main limitation of the method of data collection is its backward-looking approach, which challenges the collection of highly detailed information through the questionnaire. For example, it might be challenging to reach persons responsible for an innovation's development that might have started several years back. To limit this problem, VTT tries to conduct proximal survey waves. Second, the object-based approach might create a bias towards more significant and novel innovations, which are presumably more commonly reported in the journals compared to more mundane, incremental innovations. Similarly, the database mainly includes product innovations introduced to the market, and therefore underrepresents process and service innovations. A common issue in object based datasets is the selection of a sample, since it is impossible to define the size of the whole set of innovations for a country.

In this study, we utilize data for the period 1985–2009, for which SFINNO contains 3272 innovations. For 34% of these (1152 innovations in total) we have questionnaire data that we use to assess VTT's role.

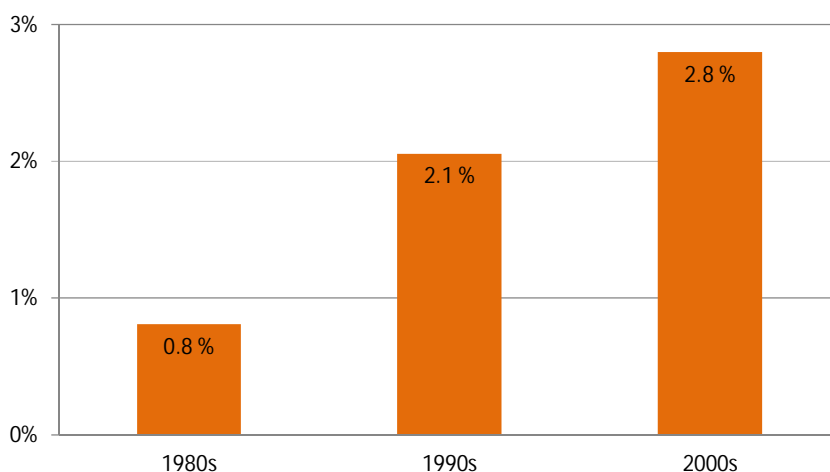


Figure 6.2. Evolution of the share of VTT's own commercialisations. Source: VTT SFINNO™ Database, 1985–2009, N=3152. Note: *Shares of the total amount of innovations for which VTT was the company that commercialised an innovation. The 1980s refers to 1985–1989, while the 1990s and 2000s are complete decades.

The importance of VTT's spin-off activities has increased steadily over time, and from 2000 to 2009, VTT's spin-off companies accounted for almost 3% of recorded Finnish innovations (see Figure 6.2). In absolute numbers, this represents 41 companies or an average of 4 spin-off ventures per year. VTT's increasing focus on spinning off R&D applications culminated in the creation of VTT Ventures. This subsidiary was founded in 2007 with the mission of generating more and better spin-off companies from VTT's research activities and adding more economic value.

Turning now to the dynamics of the importance of VTT's R&D cooperation activities, the picture is a generally stable one. In other words, our dataset of Finnish innovations shows that R&D collaboration with VTT was as important during the last decade as it was in the 1990s and 1980s (see Figure 6.3).

It is more difficult to assess, however, whether this message is an optimistic one. What is important to stress is that the evidence presented here is based on the quantity of innovations in terms of their numbers in specific time-periods, but not their quality, importance, or project size. A second and related issue is the fact that R&D and technological innovations increasingly need to be complemented with other capabilities (e.g. services) to have a maximum impact on a company's performance. In other words, companies do not only depend on technological innovations to be successful but rather on a complex mix of technological and non-technological capabilities. To that end, VTT has taken steps to broaden its service offerings (e.g. in the area of service innovation). Another question, however, is whether cooperation with other partners could increase the maximum impact on companies and on society generally.

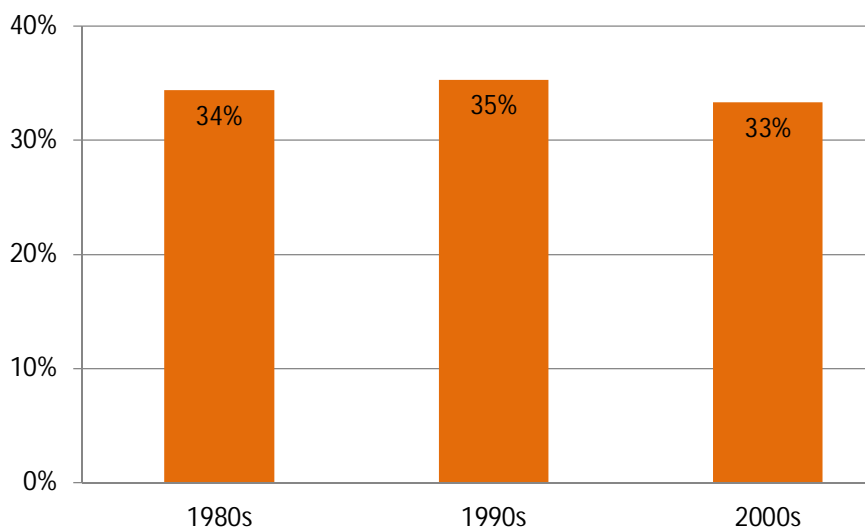


Figure 6.3. Evolution of the share of innovations where VTT was a collaboration partner with impact*. Source: VTT SFINNOTM Database, 1985–2009, N=1025. Shares of the total amount of innovations for which VTT played a minor significant, a significant, or a very significant collaboration role in developing innovations.

Comparing the importance of VTT with other Finnish public research organisations clarifies its significance for the Finnish innovation system. Two other key observations emerge from Figure 6.4. First, Finnish public research organisations are more important for Finnish companies than foreign ones. Second, the 10 Finnish universities, taken as a whole, are the most important collaboration partners for Finnish companies, while VTT is the second-largest partner in the Finnish research landscape. The larger role of Finnish universities must be put in perspective, however, as they represent a number of individual institutions. Unfortunately, the data did not allow us to make a comparison with individual universities. It should also be noted that the most important collaboration partners for Finnish companies are Finnish and foreign customers and domestic subcontractors.

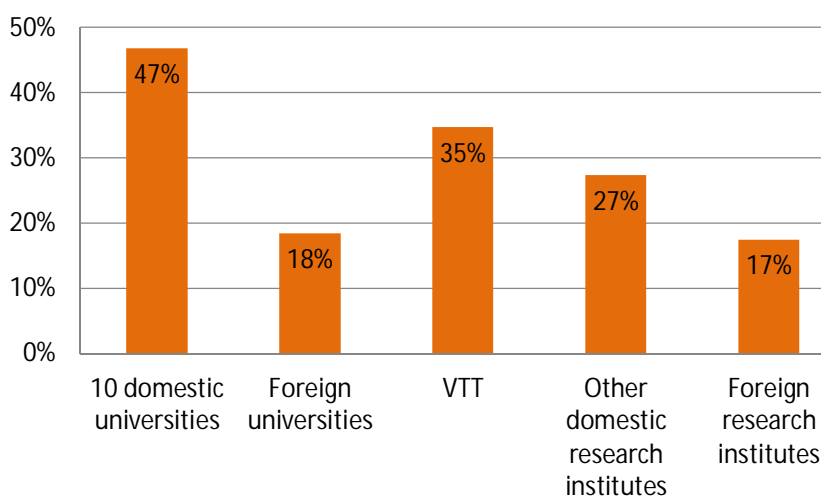


Figure 6.4. The role of VTT and other RTOs for Finnish innovations. Source: VTT SFINNOTM Database, 1985–2009, N=1077. Shares of the total amount of innovations for which selected collaborations partners played a significant or less significant role in developing innovations.

The role of collaboration with VTT can be expected to vary over different types of innovations. Innovations can be categorised based on their novelty for a company or for the market, but also based on the type of know-how they include. The shares in Table 6.1 show that VTT has been mainly driving innovations that are either totally new or represent a major improvement for a company, which appears to highlight VTT's role as a knowledge provider. In addition VTT's importance is most salient in innovations that are new to the global market and less so in those that are new to the Finnish market. Another aspect of VTT's significance for companies is that innovations in which VTT played a significant role are most often based on the commercialisation of companies' core technology and the development of production methods. Both of these can be argued to lie at the heart of many companies' competitive advantage.

Table 6.1. VTT collaboration role versus innovation types. Source: VTT SFINNOTM Database, 1985–2009, N=1053. Shares of the total amount of innovations for which VTT played different kind of collaboration roles in developing innovations (no role, a minor role, or a significant/very significant role).

The importance of VTT for different types of innovations	Importance of VTT collaboration			Total	N
	No VTT	Minor role	Significant role		
NOVELTY TO THE FIRM					
Totally new	65 %	18 %	17 %	100 %	658
Major improvement	64 %	21 %	16 %	100 %	331
Incremental improvement	78 %	13 %	9 %	100 %	64
MARKET NOVELTY					
New to domestic market	74 %	14 %	12 %	100 %	231
New to global market	63 %	20 %	17 %	100 %	739
TYPE OF KNOW-HOW BEHIND INNOVATION DEVELOPMENT					
Commercialisation of core technology of the firm	58 %	21 %	22 %	100 %	390
Development & integration of components/modules	68 %	20 %	12 %	100 %	344
Development of production methods	67 %	16 %	18 %	100 %	171
Commercialisation of service concepts	84 %	8 %	8 %	100 %	73
Other	74 %	18 %	9 %	100 %	68

Innovations can also be categorised based on their complexity. This is useful because the complexity of an innovation increases when a diverse set of knowledge domains is required for its development, calling for more resources and time than simple innovations. Table 6.2 confirms that the importance of VTT mainly lies in the development of complex innovations, and to a lesser extent those of medium complexity. Thus, it seems that VTT is more often deeper involved in innovations with higher complexity. Furthermore, more ambitious and more challenging innovation projects naturally take more time to complete.

Table 6.2. VTT's role in the development of innovations of varying degrees of complexity. Source: VTT SFINNOTM Database, 1985–2009, N=968.

Innovation complexity	Importance of VTT collaboration*			%	N
	No VTT	Minor role	Significant role		
High	49 %	16 %	35 %	100 %	37
Medium	65 %	20 %	16 %	100 %	765
Low	72 %	13 %	15 %	100 %	166

Table 6.3 also shows that VTT's key complementary strength lies mainly in innovation projects with development times longer than 3 years.

Table 6.3. VTT collaboration role versus innovation development times. Source: VTT SFINNOTM Database, 1985–2009, N=936. *Shares of the total amount of innovations for which VTT played different kind of collaboration roles in developing innovations (no role, a minor role, or a significant/very significant role). Development times for innovations are calculated as the year of commercialisation minus the year when the basic idea originated.

Role of VTT collaboration	0 to 1 years	2 to 3 years	4 to 5 years	6 to 10 years	More than 10 years	N
Significant	11 %	15 %	24 %	20 %	25 %	154
Minor significance	20 %	18 %	17 %	19 %	19 %	171
No role	70 %	67 %	59 %	61 %	56 %	604
Total %	100 %	100 %	100 %	100 %	100 %	
N	256	368	135	122	48	929

A different question is what the main driver behind the innovations in which VTT has been involved is, since innovation projects can spring from a multitude of opportunities. In line with what we would expect based on VTT's strengths, Figure 6.5 shows that the most important driver of VTT-related innovations relates to opportunities afforded by developments in science and technology. More specifically, it seems to be public research, licences, and scientific breakthroughs that drive the innovation activities of the companies that call in VTT's expertise to assist in their development. For VTT-related innovations, other categories of drivers, such as competition and market opportunities, also seem important. In these second and third categories, it is mainly public procurement, regulation, and environmental considerations that spark VTT customers' innovations.

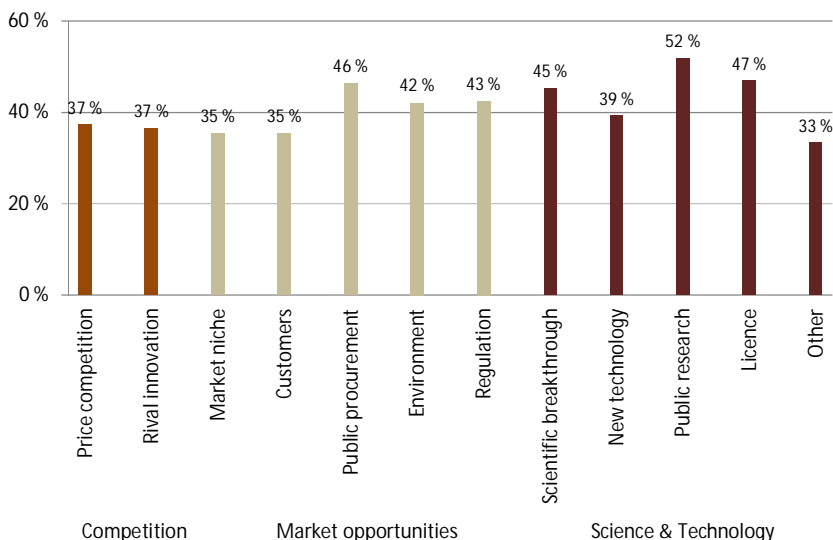


Figure 6.5. Driving forces behind innovations developed in collaboration with VTT. Source: VTT SFINNO™ Database, 1985–2009, N=968. Shares of the total amount of innovations for which VTT collaboration contributed (either a minor role, a significant or a very significant role).

In a small open economy like Finland, the internationalisation of innovations is crucial to company growth and survival, and as such can be expected to be widespread. Figure 6.6 shows that during the last decade the proportion of innovations that have been internationalised consistently reached 60% or more. But more importantly, the figure also reveals that innovations where VTT played a role have been more frequently internationalised, particularly since 2005. As a note of caution, however, no strong conclusions should be drawn here due to the small differences in the data.

Box 6.3. Data availability and the data needed for analysing the impact of VTT

As discussed in Chapter 4, the impact of an innovation system player like VTT should be analysed with a healthy mix of different methods to ensure the robustness of the obtained results. One of the key methods to be used is quantitative analysis. In this box, we will briefly describe which kinds of data are currently available for analysing the impact of VTT, and we single out future data needs that should be taken into account to provide solid future impact assessments.

To analyse the output and the impact of VTT, the following data can be used: (1) Organisational-level data on VTT's inputs and outputs, (2) Innovation-level data obtained from VTT's database of Finnish innovations (the Sfinno survey), and (3) Client-level data such as company data from the business register of Statistics Finland and other official company-level data merged with survey data obtained from client surveys. This categorisation implies that broader impact interviews with stakeholders from industry and policy-makers are considered qualitative data.

Data that capture the VTT inputs (such as R&D investments and human resources) and VTT outputs (such as refereed journal publications, patents, innovations, and spin-off companies) are readily available and can give us insights into the efficiency of VTT's operations. To analyse the dynamics of the composition of VTT human capital, it is important to make a clear and detailed distinction between different categories of researchers and non-researchers. This is important to further optimise cooperation between technical and non-technical capabilities with the aim of maximum value creation.

VTT's Sfinno database of Finnish innovations is a unique and valuable source of information for analysing the impact of different players on Finnish innovations. Innovation-level data have indeed seen a revival in interest and several countries such as Sweden and the Netherlands have launched new data collection initiatives in this field. It is important to keep the Finnish innovations database updated and pay sufficient attention to both its maintenance and exploitation. The database mainly contains product innovations and it would certainly be useful to start collecting information on complementary types of non-technological innovations, such as service and business model innovations (see Robin and Schubert 2013).

One of the main roles of VTT is to create value for customers. Client-level data allow us to see what happens to clients after they team up with VTT. Currently, VTT runs an annual client impact survey covering a representative sample of its clients.



Figure 6.6. Evolution of the share of Finnish innovations that have been internationalised: the role of VTT collaboration. Source: VTT SFINNO™ Database, 2000–2009, N=250. Note: Evolution (by commercialization year) of the shares of the total amount of innovations (1) for which VTT played a collaboration role in developing innovations (either a minor role, a significant or a very significant role) (darker bars) and (2) for which VTT did not play a collaboration role (lighter bars).

In summary, analysis of the SFINNO database has provided us with a number of insights into the role that VTT plays in nurturing Finnish innovations. VTT has been an important collaboration partner for companies that have developed innovations that they have then brought to market. Over a time span of 24 years, VTT has collaborated in about 34% of all observed innovation projects, and this percentage has remained stable over the entire period.

In comparison to other types of potential partners for Finnish innovators, VTT is the second-most important innovation partner after all Finnish universities combined. VTT increasingly also contributes innovations that originate from its own in-house R&D, and has accounted for almost 3% of Finnish innovations in recent years.

As a collaborative partner and a provider of expertise and know-how, VTT's role is considered especially important in the development of highly complex innovations, and VTT's significance is also deemed higher in the context of developing more novel innovations.

Another question that we looked at is the type of know-how behind the innovations in which VTT played a role in their development compared to those innovations in which VTT played no part. It appears that VTT's role was most often linked to developing companies' core technology and production methods, which are both considered strategically important.

In the context of the small domestic market for Finnish innovators, exports are a crucial objective. Here, we observe that the innovations in which VTT played a role have been slightly more frequently internationalized than those in which VTT did not take part in development since 2005.

7. Case examples of VTT's roles in promoting industrial innovation

7.1 Introduction

This chapter aims to shed light on VTT's various roles and the added value and wider socio-economic and ecological impact of case examples that illustrate VTT's participation in processes leading to innovations, as well as highlight the various roles that VTT has pursued. Innovations can be considered one of the most concrete indicators used for measuring the performance of an innovation system, and for this reason it is important to address individual innovations and processes leading to innovations when assessing VTT's roles and impact within Finland's national innovation system.

Innovation is a catalyst for change, at both company and industry level. However, changes in industry cannot typically be attained by a single actor or innovation alone, but require multiple actions in the surrounding environment and industries (Abernathy and Utterback 1978). The technological improvements that lead to renewing an industry can be observed as long-term innovation chains in which industry and research work together ideally. Industry renewal occurs as a result of small incremental and large disruptive changes over a long period of time (Tushman and Anderson 1986). Technological renewal depends strongly on the interaction of history, individuals, and market needs. Innovations are usually linked to earlier decisions and path dependency. Research organisations such as VTT have an important role in these chains by developing technologies and applications for industries. Due to the long-term perspective of change, the impact of individual innovations or technologies are difficult to observe as they are often part of larger systemic change. Many of the technologies that VTT develops target Europe's

grand challenges⁴, which are a good example of a need for change that cannot be solved by one technology, scientific discipline, or sector alone⁵.

In this complex puzzle, VTT is an important actor, linking Finnish applied research closer to the international research arena, providing leading scientific expertise, as well as testing facilities and expertise to identify applications for new technologies.

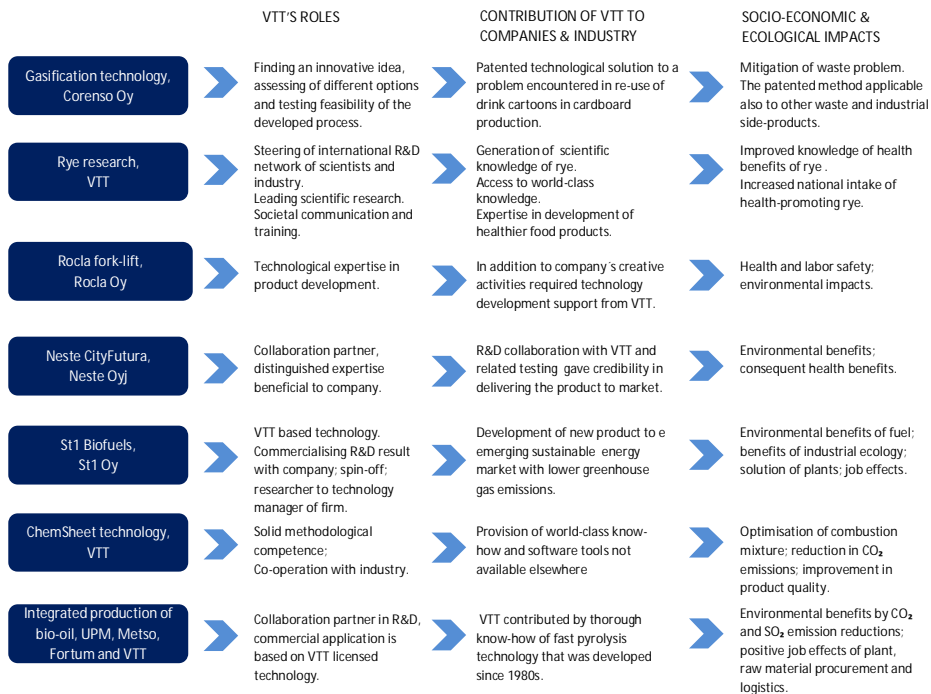


Figure 7.1. Summary tables of VTT cases. Source: VTT.

These case examples clearly show that VTT has multiple roles, even in individual innovation development processes. This highlights the importance of assessing the contribution and impact of VTT's activities by qualitative means, rather than concentrating on quantitative indicators alone. Much of the societal, economic, and ecological impact we can observe is not quantifiable. Future impact studies

⁴ http://ec.europa.eu/research/era/pdf/eg7-era-rationales-final-report_en.pdf [accessed 21.2.2013]

⁵ Study to assist the European Research Area Board: Investing in Research and Innovation for Grand Challenges. Joint Institute for Innovation Policy (JIIP), 2012. http://ec.europa.eu/research/erab/pdf/erab-study-grand-challenges-2012_en.pdf [accessed 21.2.2013]

should systematically take qualitative issues into account. In practice, this will call for deeper qualitative analysis of individual case examples.

These case examples have been selected to illustrate the multitude of roles that VTT pursues. They have been identified primarily from the Sfinno database and the authors' existing material. Table 8.1 summarises the main roles that VTT has performed in technology or innovation development, highlights the added value of those activities to companies and industry, and pinpoints the materialised or attained societal, economic, and ecological impact.

7.2 Using accumulated knowledge in gasification technology to solve a problem in recycling drink cartons – VTT's role in developing Corenso United's ECOGAS™ process

VTT has been actively conducting R&D on gasification technologies for biomass and waste since the early 1980s. By the mid-1980s, these R&D efforts had led already to commercial applications. Working together with a Finnish SME, VTT developed a biomass gasifier technology that was used in a number of plants built in Finland and Sweden between 1985 and 1986 – the technology was mostly used for small-scale district heating plants. VTT continued working on various gasification technologies in the years that followed, as well as on methods for gas cleaning.

VTT's accumulated expertise in biomass and waste gasification enabled it to quickly develop a solution to a problem Corenso United Oy Ltd was facing at its Varkaus plant in 1996. Corenso contacted VTT to help in solving a problem that had been encountered when using recycled multi-material drink cartons – typically consisting of wood fibre as well as plastic and aluminium foils – as a raw material for cardboard production. The company was separating wood fibre for re-use, whereas plastics and aluminium were burnt in a steam boiler. The process used to separate and remove plastics and aluminium from the wood fibres of the drink cartons soon turned out to be non-functional – firing the aluminium fouled the boiler and combustion had to be stopped. An alternative ecologically and economically viable method was needed.

Corenso was aware of the expertise available at VTT, as the two organisations had collaborated during the building of the cardboard production plant specialising in the use of recycled drink cartons in 1995. It was VTT experts who suggested the idea of looking more closely at gasification technology, which was one of the three solutions considered for tackling the problems caused by the aluminium foil in the cartons.

Corenso initially funded laboratory-scale testing carried out at VTT. These assessed the viability of four different methods for gasifying the plastics and aluminium contained in the drink cartons. The aim was to find a solution that enabled plastics to be gasified and combusted in a power plant, while allowing simultaneously removal of the aluminium for recycling. During the next phase, the feasibility of different process options were tested at VTT's Process Development Unit. The results showed that a solution based on BFB gasification technology would best

suit the problem at hand. A process technology supplier, Foster Wheeler Energia Oy, was involved in the project and during the final phase industrial-scale piloting of the developed solution was commenced at Stora-Enso's plant in Varkaus.

Successful testing and piloting of the new gasification process contributed to Corenso's decision to build a new gasification plant utilising the process at its core board mill in Varkaus. The plant started operations in 2001 and was the first commercial industrial-scale application of the gasification of aluminium-containing plastics internationally. The process innovation allowed the company not only to reuse the wood fibre from the cartons as a raw material in core board manufacturing, but simultaneously to gasify plastics into energy and recover aluminium for recycling. At the same time, the new process – known as the Ecogas Process – provided an answer to the tougher environmental requirements in the key market areas of Stora Enso, Corenso's parent company. Stora Enso is one of the largest producers of packaging board for the consumer market globally.

Long-term research and development on biomass and waste gasification at VTT and the accumulated know-how in the field made it possible to react swiftly to the problem faced by Corenso. A VTT expert had had the idea of applying BFB technology to waste gasification prior to the Corenso contact and a pilot process for gasifying waste was carried out. As a result, the project progressed from laboratory-scale work to industrial-scale piloting within a year, an exceptionally short time in developing industrially applicable process technologies.

VTT was awarded a patent for one of the four versions of the developed gasification process. The patented method can be applied to other waste and industrial by-products that include aluminium or other similar metals that melt at low temperatures.

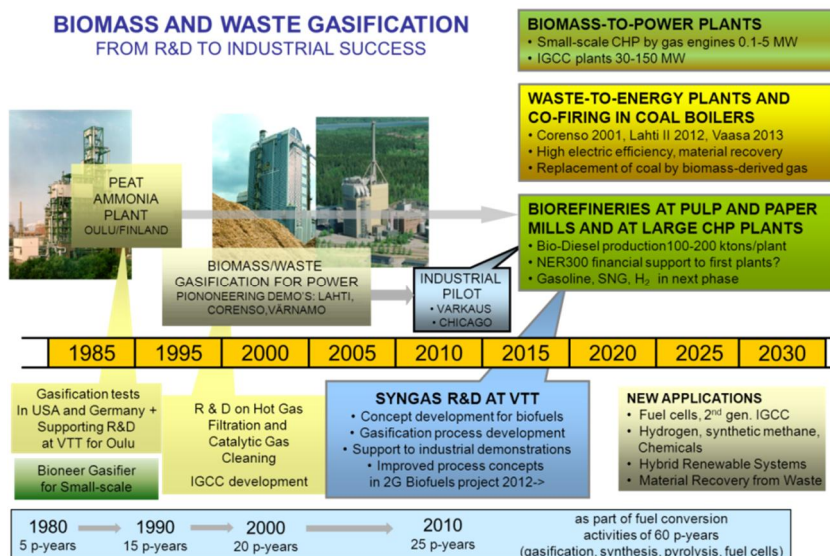


Figure 7.2. Development of biomass and waste gasification expertise and technologies at VTT since 1980. © Esa Kurkela, 2012.

Since the project, VTT has gradually expanded its R&D activities in the gasification of biomass and wastes in close collaboration with industrial partners (see Figure 7.2). Global challenges related to sustainable development and the need to find ways to replace non-renewable sources such as coal and oil in energy generation have made this work ever more topical.

Box 7.1 Contribution of VTT to Corenso

The Corenso case illustrates how a long-term strategic development of competence in a technology area is required to swiftly tailor innovative solutions to the needs of industry customers. The added value brought by VTT to the client crystallises three issues; 1) the provision of an innovative idea to solve a problem encountered in an industrial process, 2) expert support and services in assessing different options for the problem at hand, as well as 3) testing the feasibility of the process at VTT's Process Development Unit before full-blown industrial development took place. In addition to the immediate commercial benefits, the patented technological solution also contributed to the more general mitigation of waste problems related to the recycling and re-use of drink cartons.

7.3 Ingredients for innovations – the role of VTT's world-class rye research

'Ruista ranteeseen – rye to the fist', referring to the high nutritional aspects of rye, has echoed in the ears of Finns for many years. Today, many Finns acknowledge rye as a good source of dietary fibre with many health-promoting benefits. This understanding is also widely shared internationally as a result of long-term research, efficient communication, and training by Finnish research organisations including VTT. Wholegrain rye is rich in dietary fibre, vitamins, minerals, and antioxidants, and has been proven in many studies to reduce the risk of diseases such as cardiovascular diseases and diabetes.

Historical roots of rye research

VTT has played a central role in taking Finnish rye research to the top of the field globally. In addition to VTT, important fundamental work has been conducted by Professor Adlercreutz and his research group on lignans and their health effects related to rye. Although VTT's first projects on rye can be traced back as far as the mid-1960s, a research strategy concentrating on examining grains in general and rye in particular was only formulated at the beginning of the 1990s. The key factor here was partly influenced by the positive results of work carried out in the brewing laboratory led by Professor Tor-Magnus Enari, where industry collaboration was common practice. The hope was to adopt this cooperative model in the food industry as well. The seeds for rye research at VTT had been planted, and deter-

mined work to produce top-quality scientific research and new innovations for industry was able to begin. Several projects on rye have continuously been running at VTT ever since, and research has focused on various aspects of rye, from improving the baking process to the health benefits and nutrition of wholemeal grain. However, the mission required a common vision from industry and academia.

Formation of national and international networks

It was clear that VTT needed partners to attain its aims to scientifically prove the health benefits of rye and bring the results to the attention of the larger population, especially as the consumption of rye and other cereals had been decreasing since the 1950s. One of the first tasks was to create an open dialogue with national industrial partners, research organisations, and academia to develop a national base for rye research. This proved successful and two strong national players in the Finnish baking industry – Fazer Oy and Vaasan Oy – were active in the rye research network since the beginning, and have invested significantly in researching the health-related benefits of rye. Tekes' food-related technology programmes have provided fruitful ground for cooperation and influenced the growth of rye research in Finland.

Since Tekes' first food-related technology programmes in the early 1990s, VTT has actively initiated and coordinated rye research at national, Nordic, and international level. Given that the other Nordic countries share an interest in rye research, the network was soon extended to cover the Nordic countries. Although research collaboration on rye within the region had been under way for many years, the founding of the Nordic Health and Rye Group in 1994 formalised this cooperation. VTT was the key actor in setting up the group and has led Nordic operations. Visions and targets were now formulated with Nordic industrial partners and academia. The operation of this group has provided a platform for lively collaborative rye research for some 15 years and produced top-quality scientific research.

The good results of the Nordic collaborative model, in which even industry competitors are able to co-operate, encouraged extending the rye and wholegrain research network even further. The EU 6th Framework HEALTHGRAIN project (2005–2009) coordinated by VTT (Prof. Kaisa Poutanen) brought together 43 research partners and some 50 private companies to see how the research results could be developed into food product innovations. This large multidisciplinary project focused on two of Europe's most important bread grains, wheat and rye. Today, communication on the health-promoting benefits of wholegrain cereal and rye are disseminated via the Healthgrain Forum chaired by VTT, which has a total of some 60 partners.

VTT has taken an active networker role, which it pursues in many large international research programmes. VTT also actively participates in the work of associations and groups that coordinate research efforts and influences decision-making at industry and policy levels, as its leading positions in the Nordic Rye Group and the Healthgrain Forum indicate. The ability to partner with leading institutes in the

field has provided VTT with complementary expertise, and the wide scope of research has given VTT a strong research coordinator role and made it an appealing partner in food product development.

One example of VTT's strategic partnerships can be found in the area of university collaboration. Although VTT has traditionally been strong in developing food processing technologies, the nutritional aspects of grains have also been one of the interest areas of VTT for over 20 years, since the concept of health-promoting foods started developing in the 1990s. Nutrition research has been particularly strengthened by the joint professorship of Kaisa Poutanen at the University of Eastern Finland in Kuopio, where she set up the Food and Health Research Centre in 2000. A series of collaborative projects since then has combined VTT's process and material know-how with clinical nutrition and human intervention studies.

Communication on the health benefits of rye

Improving national health cannot be attained by scientific results alone, since consumers are the ones who make the ultimate decision to buy healthier food products such as wholegrain rye bread. For this reason, efficient communications and educating the public are an important aspect of research aimed at achieving a high level of societal impact.

Active dissemination of information on the health-promoting benefits of rye products has been part of VTT's rye research since the start. Industry collaboration is an example of how research results are disseminated to food companies. One way to communicate scientific research results and make rye research known among the wider public is via conferences and symposia, an area in which VTT has been particularly active. The first international symposium on rye was organised by VTT in the late 1990s, and VTT has been engaged in arranging several similar events ever since. VTT researchers have not only participated in scientific events, but have also spoken at various symposia and events, given interviews, and written popular articles for non-scientists, and established a website to tell people about the results of their research.

The food industry in the new millennium has been challenged by the longer-than-expected approval process covering health claims at EU level, which has also complicated communication activities related to the health benefits of rye. Finally in 2011, the EFSA (European Food Safety Association) certified rye fibre's claim for sustaining normal intestinal health. This was the only health claim approved for rye, many claim applications were rejected to the surprise of researchers and industry, as happened with many other health claims related to other foods and ingredients.

VTT has participated in discussion on the health promoting benefits of rye by providing scientific evidence. The key messages highlighting the benefits of rye has been repeated in the press for decades, almost to the point of exhaustion. However, by the 2000s rye researchers could see that their hard work had paid off when the consumption of rye in Finland finally stabilised. Thanks to efficient com-

munication and education, the health-promoting benefits of rye are also nowadays known outside the Northern European rye belt. Even though rye's health claims were not officially approved, the scientific evidence has not gone anywhere and research on the health-promoting benefits of rye will continue to highlight the mechanisms explaining the epidemiological evidence supporting the health benefits of wholegrain and grain fibre, such as that contained in rye products.

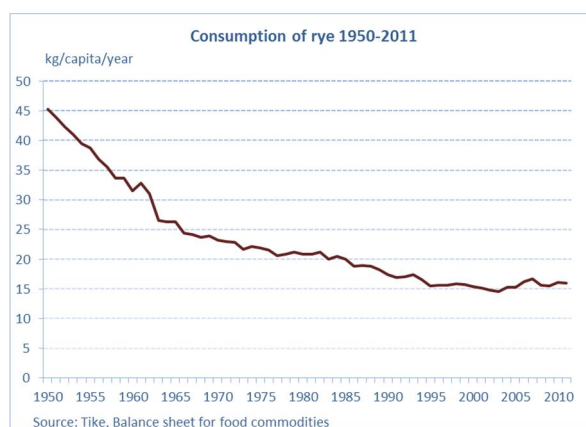


Figure 7.3. Rye consumption in Finland 1950–2011.

VTT's research leads to innovation

World-class scientific research is a prerequisite for novel food innovations, the kind of research that VTT has been able to maintain in the rye area for years. VTT's research in the early 2000s has helped develop processing techniques that affect the taste of wholegrain products and improve their health-promoting effects. To ensure that wholemeal products are popular as part of a healthy diet, their flavour and texture must meet the expectations of today's consumers. Using milling technologies, enzymatic modifications, cereal fermentation, and more recently extrusion, VTT has developed new technologies for producing rye-based foods that combine healthiness with good palatability. These kinds of scientific advancements achieved at VTT have resulted in better-tasting and healthier food products, such as Fazer Ruistoast and Vaasan TaikaRuis white bread with the health benefits of wholemeal rye.

Fazer Ruistoast, commercialised in 2005, was the first soft white bread on the market that had the health-promoting ingredients of rye. The innovation behind it is called Fazer Rye Fibre – and required over 10 years of collaboration with VTT. VTT's research input on the taste of rye was highly beneficial in the development of Fazer Rye Fibre, as many younger consumers in particular do not like the strong, bitter taste of rye. One of the problematic areas in the development of Fazer Ruistoast was baking, which required extensive knowledge on baking pro-

cesses and recipe techniques. This challenge was solved at Fazer Bakeries. The development of Fazer Ruistoast is a good example of collaboration where leading research conducted at VTT has helped the Finnish food industry develop novel innovations.

While Fazer Ruistoast is an example of cooperative research and development, Ruisvoima Oy's food innovation, Tempo Rye Snack, is an example of product development based on an invention developed at VTT. The main ingredients of Tempo Rye Snack are rye bran, which is the most nutritional part of rye, and flaxseed rich in omega-3. This combination was the result of experimentation with around 200 different recipes. VTT took part in the development process of Tempo Rye Snack in many ways and its expertise, especially in production processes, as well as in texture and flavour, were influential in the final outcome. Primula Bakery also participated in developing rye bran processing. Some aspects of product development are demanding for smaller companies, and collaboration with a larger partner such as VTT is highly beneficial. In the case of Tempo Rye Snack, VTT facilitated the piloting of production and also helped in formulating the patent application. Rye bran and its good health-promoting qualities will continue to be the base of Ruisvoima Oy's product development in the future.

Although R&D in the food industry has decreased dramatically since the 1990s, when many food companies shut down their basic research functions, maintaining only product development in-house, scientific research aims to develop novel innovations in the future as well. Bioprocessing and fractionating technologies for rye and fibre-rich rye bran aimed at developing even better-tasting and healthier ingredients for rye products are currently on VTT's research agenda and hopefully new innovations will emerge in these areas in the future as well. However, it is eventually up to a company's own product development processes to take advantage of research results achieved at VTT in combination with its extensive international research networks.

Improved public health – the health benefits of rye

Several studies (cf. Case study references in References) show that eating wholemeal products, such as rye, provides protection against cardiovascular diseases and type 2 diabetes, as well as improved intestinal health and weight control. These are serious chronic diseases not only in Finland but globally, and treating them generates extremely high costs – costs that could be partly avoided if more people were to eat a healthy diet containing a high level of wholegrain products. A higher intake of health-promoting wholemeal products increases well-being and health, and helps prevent diseases, saving on health care expenses and enabling health care to shift, at least in part, from curing illness to prevention. All these actions eventually result in better quality of life in the society.

Despite the limited EFSA approval given to rye-related health claims, research on rye and wholegrain is set to continue at VTT in cooperation with its international network of universities and industrial partners.

Box 7.2 Contribution of VTT to world-class rye research

VTT has been an active initiator in developing top-class research on rye, nationally and internationally. It has brought the results of scientific research to industry, which has resulted in the launch of a number of new health-improving food products. Communication and training on the health benefits of rye has been active for more than 20 years.

7.4 Rocla fork-lift: VTT's technical knowledge played an important part in the radical renewal of the product⁶

Rocla is a manufacturer of warehouse trucks, counterbalance trucks, and automated guided vehicles (AGV). In addition to tangible products, the company supplies a wide range of services to maintain the high availability of equipment within customers' equipment fleets. Although Rocla aims to be a technological forerunner in its business, virtually all its competitors use by and large the same technologies in manufacturing trucks (batteries, driving units, electronics, etc.). Hence, in order to succeed, Rocla needs to differentiate itself in other ways than technologies, and has done so by introducing a design-driven new business concept that has enabled the company to gradually move from a laggard position to that of a forerunner in its market niche in recent years.

The design-driven concept at Rocla is more than design in the traditional sense, emphasising mainly visual elements. Besides the awarded design the concept encompasses high usability and ergonomics, user-friendliness, intelligent solutions, safety, well-being, pleasure, and emotions, as well as the health of truck drivers and, by extension, increased productivity.

⁶ The description is based on Oksanen et al. (2010).



Figure 7.4. Roclá warehouse trucks. © Roclá.

In line with an extensive focus on the design-driven concept, cultural aspects and differences in values and the preferences of truck drivers are seen as important aspect to be taken into account in product development. Information on these issues is collected using a variety of different methods. Close observation of work processes and practises in an actual warehouse working environment has become an integral part of Roclá's design process, as has spending leisure time with truck drivers. As a result, Roclá utilises the different preferences of drivers in product development to develop solutions that allow drivers to tailor their trucks in various ways. A driver can, for example, select between a more traditional driving wheel and a Playstation-type of joystick.

The health of truck drivers are also of importance in product development. Data on the behaviour, motivation, and health status (e.g. heart pulse) of drivers is collected during the working day. The daily activities of drivers in warehouses, for example, is monitored using helmet cameras. Data is recorded, analysed, and utilised when deciding what should be improved or done differently and how products, the user interface, logistics, etc. should be developed. The aim is to simplify the human-technology interface and make it easier to drive a truck without reading a pile of detailed manuals first.

To summarise, Roclá's design-driven concept has put the focus on the end-user – the truck-driver – in product development in business-to-business context. The case highlights the importance that relatively minor issues in the everyday working environment can have in terms of potentially large gains. By paying attention to drivers' preferences, Roclá has been able to improve their productivity and help the company differentiate its offering from those of its competitors in mature markets.

Box 7.3 Contribution of VTT to Rocla's warehouse truck technology

VTT has supported the technology development of the Finnish truck manufacturer, Rocla, through numerous collaboration projects. These include a forklift utilising radio frequency identification technology (RFID) that recognises its load automatically. This RFID forklift is now in the pilot stage and is being tested at Ekokem Oy's plant in Riihimäki, Finland.

7.5 Neste CityFutura: VTT as an active collaborator in development and testing⁷

Neste Oy was established in 1948 as Finland's national oil company to ensure the country's access to fuel. This entailed the building of refineries and developing the necessary technology. Neste grew into a large company by Finnish standards and held a legal import monopoly until market liberalization in the 1990s. The MTI and the company understood the need to shift the company towards greater competitiveness in an open energy market in the 1980s.

CityFutura was a large-volume product and an incremental innovation, aimed at national and international markets. CityFutura was launched in June 1991. Key factors affecting the development of the innovation were fierce international competition in the automotive industry, in which competitive technological development plays an important role. Technology was shifting towards increasingly efficient engines, from carburetors to direct injection, increasing the number of valves, and by developing more effective combustion. The future vision of fuel properties and quality was based on US standards; globally, the strictest emission requirements including the use of catalytic converters were implemented in California, a forerunner in environmental awareness. Other factors included the forthcoming membership of Finland in the EU, surveying future directives and weather conditions i.e. the cold winter in 1987 (which caused problems for Neste while other companies, such as Teboil, managed well, etc.).

Environmental issues, especially the prevention of air pollution, became important competitive factors in the car industry in the 1980s. Attention was paid to the need to eliminate lead from petrol (with the help of methyl tertiary butyl ether, MTBE) and to developing catalytic converter technology. In the 1990s, the emphasis shifted to reducing greenhouse gas and particle emissions, as well as the potential side-effects of MTBE. From an environmental perspective, Neste also challenged the oil refining industry's production of fuels. The domestic competition for customers was also fierce.

To protect Finland's national market, the state gave Neste a monopoly on the wholesale trade of petrol in the 1950s but due to the liberalisation of the energy

⁷ The case is based on Hongisto et al. (2001) and on Hyytinen et al. (2012).

market, the company lost its monopoly on crude oil in the early 1990s. In the 1980s, to prepare for this likely upcoming change, the company started strengthening its future market position, by acquiring Finnish fuel marketing companies (Kesoil, Finnoil, Union). Import protection on petrol and wholesale diesel ended as a result of the end of bilateral trade with the Soviet Union. However, problems started to accumulate in the late 1980s: the company's quality image was poor, taxation was getting tougher, demand was declining, and exports faced problems. As liberalisation approached, Neste set itself the target of changing the company's position to ensure its future competitiveness and employment. This called for a competitive new product and the processes needed to produce it.

The background for cleaner fuels dates back to the 1950s, with the decline of urban air quality, the emergence of stricter emission requirements, and the development of reformulated petrol in California. Neste had begun development of a new-generation, more environmentally aware petrol already in the 1970s, but its customers did not adopt CityFutura quickly. They lacked information on the fuel and active advertising and public information was needed. As one of the interviewed experts stated, the media in the early 1980s was simply not interested in cleaner fuels. Although it had already been possible to accomplish the process in technical terms, following the completion of an MTBE unit in Porvoo in 1981, the market was not ready to pay a higher price for petrol of a higher environmental quality.

For Neste, the following factors affected the development of the innovation. During its time as a monopoly, the company had invested in R&D and other areas outside its main business activities in oil refining and plastics. These areas included electric vehicles and dispersed energy production technologies. As the change in the market situation became evident, Neste saw the need to secure its competitiveness through a product strategy based on R&D that would place it ahead of its competitors. This took place by differentiating its products from those of its competitors and by branding its products. The company favoured technological superiority and quality. The updated product portfolio can be characterised by a successful combination and alignment of strategy change and environmental arguments.

The specialized niche strategy was also made possible due to the international competition situation: large global oil companies did not have the opportunity to make the investments required for reformulated products. Competitors criticised the tax relief granted to CityFutura petrol and the European refining industry objected to the introduction of a product that would have required major investments by them. Neste's advantages were that it was small and agile compared to its competitors, as its strategic decisions could be quickly implemented, although it lacked the market power of large companies. Neste adopted a competitive, proactive strategy based on R&D to put it ahead of its competitors. A similar competitive strategy was also applied to the rest of the company's traffic fuels (including CityDiesel).

"The product strategy followed with CityFutura, based on high-quality products, kept the company competitive and a market leader in Finland. If this radical change to product strategy had not been made, large European production plants

would have been in a better position than Neste due to their greater production capacity" (cf. Case study references in References).

Neste was able to benefit from the in-house integration of product development staff and environmental expertise in its successful, environmentally friendly innovations. In the early 1990s, the head of the wholesales business was also responsible for product development and it took a lot of work to introduce, and get acceptance for, a new product strategy. Subsequently, product development was organised on a broader basis by a steering group for product development, consisting of divisional directors. In interviews, experts also emphasised the role of employees' motivation. Articles in *Tekniikan Maailma* magazine made the new product well-known among the general public.

If compared to conventional petrol, the additional cost of producing CityFutura was slightly higher per litre. This was caused by the price of MTBE which was more expensive than other fractions. In addition to Neste, other fuel distribution companies also bought the new fuel but without the price premium thanks to tax relief. The majority of petrol sold in Finland was supplied via Neste and, accordingly, this was not the best alternative for market companies in economic or qualitative terms.

Neste's annual fuel-related R&D expenditure was FIM 15–18 million (about 50% went on petrol and about 50% on diesel). Together with refinery technology development, the annual budget was FIM 55 million. Annual funding from Tekes was FIM 1.5–2 million and was used mainly for research and test services provided by VTT.

The background factors affecting the development of CityFutura were the conclusions made by the MTI related to industrial policy and competition policy, and aimed to change the role of Neste in a controlled way. Tax relief, a central policy instrument, was justified for environmental reasons. The work of a committee considering the use of economic instruments to promote environmental protection was also involved. Tax relief linked to fuel quality was designed to favour cleaner fuel at the expense of other fuels. The tax change can be interpreted as a pro-environment statement. It was based on real emission reductions and was neutral with respect to the raw materials used. However, it was not based on life cycle thinking because the tax relief (5 pence per litre) did not make it economically possible to add a bio component (e.g. ETBE made from grain) to fuel, for example. CityFutura made reference to a regulation that others had to follow. With respect to technology policy, a central instrument was the participation of companies in Tekes' SIHTI technology programme and related public funding, with VTT and Alko as Neste's partners.

CityFutura was of strategic importance to Neste. The knowledge required for the new product was developed on the basis of long-term, in-house fuel research, which Neste wanted to protect from competitors, so there was neither the need nor the willingness to share this knowledge with others. In the development of reformulated petrol's qualities, Neste was a forerunner, starting production of MTBE in 1990. The company carried out research collaboration with VTT to develop its capability to measure tailpipe emissions, to generate additional visibility

for measurement results, to ensure the impartial reliability of the results, and to develop methods for determining environmental impact. The expertise of Alko was lined to the use of ethanol as a fuel component. The emphasis on collaboration with VTT and Alko was in the final stage of the innovation process. There was also collaboration with catalytic converter manufacturers and car engine manufacturers.

CityFutura's quality is a product innovation and the process changes made were not essential. The reason for the process changes and process optimisation made at the time was due to higher crude oil prices. The innovation can be defined as an incremental innovation, and was an essential improvement and resulted in a cleaner product that replaced earlier-generation products. Neste was the first company to produce reformulated petrol for the European market at a time when other companies were not prepared for change on the same scale.

From Neste's perspective, tax relief made it possible to introduce a product with favourable qualities with respect to health and the environment, and accelerated the process. As figures on the share of wholesale trade indicated, tax relief did not give any complete import protection to the domestic product, although Neste's wholesale share increased after tax relief was introduced. The main reason for this was that other companies' refineries could not cost-effectively produce products of the same quality that Neste offered to Finnish consumers.

The personal roles and commitment of key people in product development proved important in the emergence of the final innovation. Among the factors slowing the process were internal resistance to the new product strategy; the absence of reformulated petrol's qualities in European markets; the import protection claims of competitors, due to tax relief; and later, the harmful side-effects of MTBE when used as a petrol component.

Production of CityFutura 99Plus, an unleaded petrol with an additive protecting engine valves (sale of leaded petrol had ended), was completed in June 1991. A related petrol innovation family was developed: Reformulated Uusi Futura petrol, with oxygen, less sulphur and benzene (April 1994); Reformulated Green Racing Futura petrol, without lead, alcohol, benzene, sulphur and a high oxygen content (June 1994); and Reformulated Futura Petrol (December 1994). The marketing of Futura Green petrol for small engines was launched in September 1996.

Box 7.4 Contribution of VTT to the development of Neste CityFutura petrol

As part of its controlled shift away from a monopoly towards a deregulated energy market, Neste strengthened its competitive role by developing a greener petrol. Public policy contributed to the development by providing tax relief for the fuel, and technology policy offered an appropriate technology programme, SIHTI, with VTT and Alko as R&D partners. VTT collaboration also proved important for testing the product and giving credibility to the product's launch in the marketplace.

7.6 St1 Biofuels: A sustainable waste-to-bioethanol concept⁸

St1 launched its decentralised ethanol production concept when it commissioned a plant based on the company's Etanolix® technology, running on bakery waste and residues. The concept is a radical innovation, and was the first anywhere to produce ethanol from waste for commercial use in motor fuel. The first plant has since been followed by four other plants around Finland. Bioethanol is made from a variety of waste streams in small, modular plants. One of the plants commissioned in late 2009 was built adjacent to a brewery and uses waste yeast and liquids from there, together with fermentable waste from bakeries and mills in the area. Yeast from the brewery used to go into animal feed and dry yeast matter will continue to do so, once the ethanol has been extracted in the Etanolix® process. The low carbon dioxide balance of the Etanolix® process has been further enhanced at this plant, as the CO₂ produced during fermentation is collected and refined by the brewery for re-use in its own production processes.

Etanolix® technology has been followed by Bionolix™, which is able to utilise mixed waste and will usher in a completely new way of making use of biowaste collected from households and commercial kitchens. Next in line will be cellulose-based raw materials. Cellunolix™ technology, now under development, will be targeted at making use of cellulosic or lignocellulosic wastes and residues, e.g. saw dust, straw, SRF or other waste fibres (see: www.St1.eu).

The ethanol production method is based on technology developed by VTT. St1 Biofuels Oy was a joint venture of St1 and VTT from 2006–2007; VTT withdrew from St1 Biofuels in late 2007 by selling its shares to St1 Finland.

The Etanolix® process is based on continuous fermentation and associated evaporation, and generates an 85% ethanol/water mixture. Depending on the raw material input, by-products can be used as animal feed or fertiliser. Dewatering is carried out separately at a high-capacity facility, such as St1's energy-efficient ethanol rectification plant at Hamina, which is capable of processing 88 million litres of 85% ethanol annually. The resulting fuel-grade ethanol can be blended with petrol for onward distribution to service stations. St1's technology separates the production of bioethanol from dehydration of the end-product, enabling small, modular units to be located as close as possible to waste sources, making waste a commercial commodity and reducing transport costs as well.

Among the primary drivers of innovation is the Kyoto Protocol and the need to reduce global CO₂ emissions, especially in the transport sector, as well as pressure to reduce and recycle waste due to EU regulations. The need to reduce CO₂ emissions spurs the demand for bioethanol and true biofuel fulfils many sustainability requirements. Producing bioethanol from waste streams is an efficient solution for recycling and the need to reduce waste and waste reduction costs. The

⁸ A slightly abbreviated version of the description of the St1's waste-to-bioethanol innovation is published earlier in Hyytinen et al. (2012).

method is based on local production from waste and does not require any land use changes. When dispersed, production is located next to waste generation so transportation costs are avoided. Depending on the raw material input, the rest of output can be used as animal feed or fertiliser. Production is based on a modular design: plants comprise modules and standard components, using light construction for easy relocation. Processing plants have a small footprint, typically 25 x 25 metres, but naturally the footprint depends on the size and scale of the plant. The method needs only minor changes in waste management when being implemented. It also has low operation costs, is highly energy-efficient, highly automated, and has the option for remote operation. Ethanol production is an increasingly competitive area and many of the features outlined above give a unique advantage to St1 when compared to other companies' ethanol production methods.

The production method has promising future perspectives internationally. The potential to mitigate the global impact of climate change is important and the growth opportunities in respect of the global prices of ethanol and the costs of waste management make the unique production concept attractive. Demand is likely to be particularly high in countries where the population, and hence the amount of generated waste, is large.

The product development project covering the planning of the construction of the first plant was supported by funding from Tekes. Funding from Tekes also contributes to on-going product development work in which St1 Biofuels is developing new processes and raw material treatment methods (ethanol production from lignocellulosic waste using the St1 process).

St1's Etanolix® method was awarded the national INNOSUOMI 08 Award in Finland, The Chemical Industry Innovation Award in Finland, and The Silver Award 2008 in Environmental Innovation for Europe.

Box 7.5 Contribution of VTT to St1's waste-to-bioethanol technology

The ethanol production process originates from technology developed at VTT and can be considered an important spin-off from VTT to a private company. St1 Biofuels was a joint company of VTT and St1 in 2006–2007, after which VTT withdrew. Production plants are modular and use waste and sidestreams from local areas. The innovation has a broad societal impact because it is the first commercial biofuel product.

7.7 Making the most of the digitalisation of chemistry: VTT's modelling and simulation tools in chemical thermodynamics – ChemSheet technology

The growth of computing power and the expansion of computational techniques have enabled the emergence of new modelling and simulation tools in complex process chemistry. The systematic and quantitative character of chemical thermo-

dynamics makes it suitable for processing using computer algorithms. As a result, computational tools, such as simulation programs, are being increasingly used by the global research community and engineering experts in elaborating new theories and practical applications to achieve new material- and energy-saving solutions.

VTT is an active research performer in the international community in developing multi-phase thermodynamic simulation tools. The first multi-phase algorithms for industrial process design were introduced in 1995 and four years later a new simulation tool called ChemSheet was launched. ChemSheet is a thermochemical simulation tool that combines the workability of spreadsheet operations with exact multi-phase chemical-thermodynamic calculations. Customised applications are defined as independent worksheets in a spreadsheet program and simulations are run directly from the spreadsheet. ChemSheet was commercialized in a joint venture with a German software company (GTT Technologies GmbH, Aachen) and today ChemSheet is used by industry and scientists worldwide.

Professor Pertti Koukkari's research team has been in charge of developing multi-phase thermodynamic simulations and ChemSheet at VTT. Koukkari's earlier industry experience in Kemira Corporation (both in Finland and the USA) led him to engage in process chemistry from a research point of view. Kemira's research collaboration with the University of New Mexico and other US universities proved to be quintessential in highlighting the opportunities and prospects offered by computational chemical thermodynamics. Simultaneously, practical industrial applications of chemical thermodynamics were developed in Finland in collaboration between Kemira, the Helsinki University of Technology (Aalto University), and Outokumpu Corporation. During this pioneering work, the methods of computational thermodynamics were adopted as a key routine of the engineering work within the companies.

In 1995, Koukkari started working at VTT and established a research group for studying thermochemical multi-phase methods and their application in advanced process simulation. Initially, the research was supported by VTT's basic funding. The first version of the ChemSheet program was then tested for various applications in a Tekes-funded project in 1997-1999. Later, practical industrial problems were solved within several Tekes programmes. Research connections have been particularly close with Aalto University, Åbo Akademi University, University of Oulu and the University of Osaka in Japan. Industrial collaboration has included both industrial partners and small service providers, such as GTT Technologies GmbH in Germany, Research Center of Computational Mechanics (RCCM, Tokyo) in Japan and Oy Process Flow Ltd in Finland.

In the 2000s, the use of the ChemSheet program family has expanded to numerous industrial applications, such as nuclear reactor safety systems, zinc recycling, steel manufacturing, and pulp and paper production. ChemSheet has helped achieve savings in the energy efficiency and carbon footprint of major industrial processes. It has also demonstrated effective recycling measures for critical raw materials and successfully using low-quality raw materials and lean materials instead conventional means of production.

In 2005–2008, Koukkari's research group participated in Tekes' Modelling and Simulation Programme (MASI). In the research collaboration with Åbo Akademi University, Aalto University, and the University of Oulu, both the ChemSheet program and more advanced methodology were further developed. Resulting from the R&D work, two new software products were released: an application for pulp washing and bleaching (CheMac) and a novel approach to design and simulate complex chemical and energetic processes in rotary kilns (FKS). FKS (acronym for Fluent-KilnSimu) combines computational fluid dynamics (CFD) with the multi-phase chemistry calculation of industrial rotary kilns. These large rotating furnaces are widely used in process industry for combined heat and chemical treatment of various materials. The kiln processes include cement-making, waste incineration, lime production and material recycling, among other applications. The unique FKS simulator, jointly developed by VTT and Process Flow, has already been utilised in optimising combustion mixtures, reducing carbon dioxide emissions, and improving product quality for various kiln-type furnaces for both Finnish and international customers.

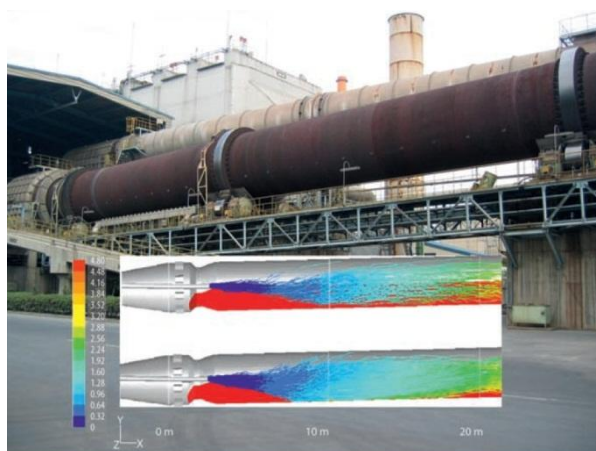


Figure 8.5. Simulation information produced by the FKS simulator for rotary kilns. Source: Pertti Koukkari, VTT (courtesy of UBE Industries, Japan and Oy Process Flow Ltd, Finland).

During the 2000s, two researchers in Koukkari's group have defended their thesis. The research group publishes 3–4 journal articles per year on average. In general, computational chemical thermodynamics is not mainstream chemistry, and research is largely conducted by a handful of universities and research organisations in Europe, the USA, and Japan. In Europe, the most prominent research groups are located at the National Physics Laboratories (UK), the Technical University of Aachen (Germany), KTH Royal Institute of Technology (Sweden), as well as the aforementioned Aalto and Åbo Akademi universities (Finland). Com-

mercial simulator programs for chemical thermodynamics are mainly provided by small university spin-offs. In terms of best available technology, VTT is a forerunner in the field of computational chemical thermodynamics and software applications.

The key area of expertise of Koukkari's research group is methodological competence that covers both computational algorithms and their connection to assessment of measured laboratory or industrial process data. Because each industry provides a limited number of potential application areas for chemical thermodynamics simulation tools, it is necessary to develop methods and software algorithms that are applicable across multiple industries. It has also been important that the group possesses computer programming skills among its researchers. Because acquiring methodological skills in highly theoretical computational chemical thermodynamics is demanding and resource-intensive, the added value of VTT's R&D efforts for the industry is obvious. Many industrial applications of ChemSheet technology are not public knowledge, however. This is due to the fact that simulation tools and results lie at the core of industrial process expertise and competitive advantage.

Box 7.6 Contribution of VTT to ChemSheet technology

In the case of modelling and simulation tools for chemical thermodynamics, the added value offered by VTT lies in its ability to provide world-class methodological skills and software tools for developing industrial processes. These skills are clustered in a handful of specialised research organisations in the world and an industrial enterprise is usually not able to develop and maintain these skills on its own.

7.8 Integrated production of bio-oil

Integrated production of bio-oil is a new technology developed by VTT together with UPM, Metso, and Fortum to produce bio-oil from biomass. The main drivers behind this innovation are the increasing price of fossil oil and environmental issues. Bio-oil can be used as a replacement for fossil fuel in district heating or lime kilns in the pulp and paper industry. The use of bio-oil also has a positive environmental impact since the energy produced from bio-oil reduces greenhouse emissions by more than 70% compared to fossil fuels.

This is a good example of successful VTT-industry cooperation with strong public funding. VTT developed the basic fast pyrolysis know-how, the integration concept (i.e. Integrating fast pyrolysis with a fluid bed boiler), and commercialised the technology together with industry (Metso, UPM, and Fortum). Tekes, the Ministry of Employment and Economy, and the EU have provided the funding for the development work. At the moment, VTT is one of the leading research institutes in fast pyrolysis globally and its testing equipment is the largest of any university or research organization anywhere.

The production process of bio-oil combines CHP (combined heat and power) with fast pyrolysis technology. CHP refers to power stations that simultaneously generate both electricity and useful heat. They typically have a fluid bed boiler (FBB) for fuel firing, in which fuel is burned in a suspension of hot bed material consisting of sand, ash, and additives. The hot sand effectively dries and ignites even demanding fuels with low heating value or high ash content, and various combinations of fuels. Strong turbulence and good mixing result in high combustion efficiency and low emissions.

FBB is an optimal source of energy for fast pyrolysis as the heated sand used in the process can also be utilised in fast pyrolysis. A small bleed of hot sand from an FBB and a separate reactor for pyrolysis is needed. Fast pyrolysis takes place in a few seconds at 500 °C in an oxygen-free environment. Any form of biomass can be considered for fast pyrolysis, but most of the work at VTT has been done on wood, because of its consistency and comparability between tests. Biomass decomposes to generate vapour, aerosols, and some charcoal-like char in fast pyrolysis. After cooling and condensation of the vapour and aerosols, a dark brown liquid is formed that has a heating value about half that of conventional fuel oil. In addition, by-products of fast pyrolysis (charcoal, non-condensable gases) can be re-used as a fuel in a CHP plant.

Research on fast pyrolysis has its roots in the oil crises in the early 1970s. In the U.S., Occidental Petroleum Corporation studied the fast pyrolysis of urban waste, but the results were not encouraging. The modern understanding of fast pyrolysis is based on the work of Professor Scott and his team at the University of Waterloo in Canada, who converted solid biomass raw material into bio-oil using bench-scale pyrolysis equipment in the early 1980s.

VTT laboratory work on the production and composition of pyrolysis oil started in 1985 in collaboration with the pioneering research team from the University of Waterloo. Bench-scale equipment was constructed and scaled up in the 1990s. VTT also participated in three IEA Bioenergy feasibility assessments in 1982-91 on liquid biofuels with Swedish, Canadian, and U.S. partners. The patent for VTT's innovative integrated fast pyrolysis of biomass was applied for in 1999 and granted in 2006. VTT participated in three fast pyrolysis pilot plants in Spain, Italy, and Finland during 1992–2002 with Union Fenosa, ENEL, and Fortum.

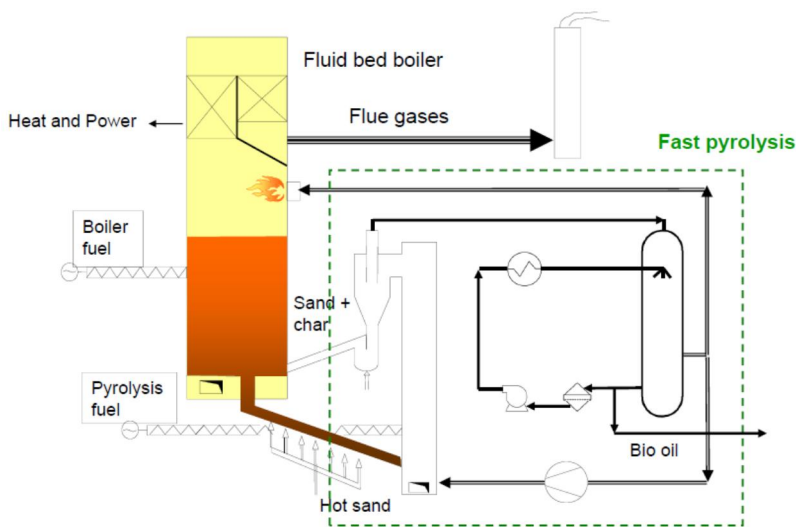


Figure 8.6. VTT's fast pyrolysis process (dashed line) integrated into a CHP plant. Source: Presentation slides by Yrjö Solantausta, 9.11.2009.

The further development and commercialisation of an integrated technology started with UPM, Metso, and Fortum in 2008. The idea was to scale-up the technology to pilot scale. After the successful pilot campaigns conducted between 2009 and 2012, Fortum decided to invest approx. €20 million in commercialising VTT-licensed technology by building a bio-oil plant integrated with a CHP power plant in Joensuu. In addition to heat and power, the plant will produce 50,000 tonnes of bio-oil a year. Replacing heavy fuel oil with bio-oil will reduce carbon dioxide emissions by 59,000 tonnes and sulphur dioxide emissions by 320 tonnes annually. It has been estimated that the bio-oil production plant project will create jobs and the effect is expected to be about 60–70 man-years in the Joensuu region. Jobs will emerge in raw material procurement, at the production plant, and in logistics. Bio-oil production is expected to start in 2013.

Box 7.7 Contribution of VTT to fast pyrolysis technology

In developing a new technology for the integrated production of bio-oil from biomass together with industrial partners, VTT used the extensive know-how and expertise in fast pyrolysis technology that it has developed since the 1980s. After successful pilots between 2009 and 2012, Fortum decided to invest approx. €20 million in building a bio-oil plant commercialising technology licensed from VTT in Joensuu.

8. Conclusions and recommendations

The focus of this study is on the legitimacy, effectiveness, and impact of VTT in general and the justification for core or basic funding from government in particular. The study has the following objectives:

- (1) to give a European and global perspective on the roles, rationale, and trends of RTOs, in order to give a context for a more detailed analysis of VTT
- (2) in the context of the Finnish innovation system, to explore the roles through which VTT contributes to innovation performance and generates socio-economic and ecological impact
- (3) to outline a toolbox of methodologies for exploring VTT's impact
- (4) to carry out a data analysis of innovations in the SFINNO database with VTT contributions
- (5) to carry out a qualitative analysis of seven individual innovations involving a VTT contribution and
- (6) to assess and make recommendations for topics and methodologies in VTT's impact studies in the future.

VTT's roles and impact are considered in the context of major global socio-economic and technological challenges, and special attention has been paid to VTT's internationalisation and to VTT's role in enhancing the innovation performance of small- and medium-sized firms.

Chapter 3 presented Figure 3.7 indicating VTT's various roles as identified by the authors of this report. Figure 8.1 below completes this picture by adding impact identified by the authors based on various official VTT documents.

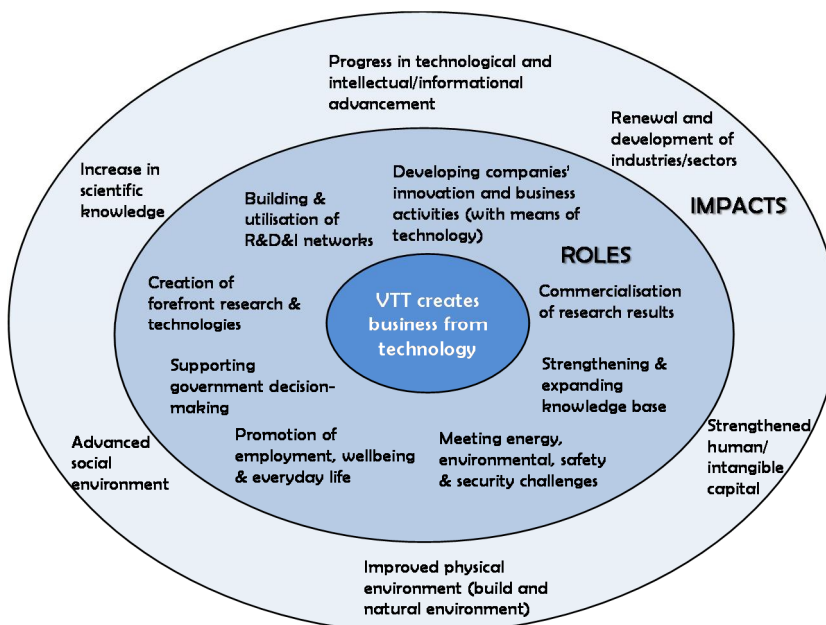


Figure 8.1. The roles and impact of VTT as identified by the authors from official VTT documents. Source: VTT.

The conclusions and results of the study in this chapter will summarise and outline various complementary aspects of VTT's various roles and impact. Section 8.1 covers the main conclusions of the study, Section 8.2 captures the key results from a quantitative and qualitative innovations analysis with VTT contributions, and Section 8.3 lists recommendations and suggestions for a broad analysis of the various roles and impact of VTT.

8.1 Main conclusions

Changing roles and rationales of RTOs in Europe and beyond

The major types of public research institutes are scientific research institutes, government laboratories, and RTOs, whose main purpose is to support innovation in business. In practice, VTT is a combination of an RTO with some government laboratories. RTOs' three-part innovation 'model' requires them to be well-connected both to the scientific and industrial worlds. Market failure is the conventional rationale for public research funding and, in the case of RTOs, capability failures are a particular legitimacy argument. The study identifies five drivers for change affecting research institutes and future policy needs in relation to them. *First*, the demand for institutes' RTI services is increasingly sophisticated as their customers are becoming more complex. RTOs are shifting from providing simple

product and process development and training for unsophisticated users towards research-intensive cooperation with sophisticated users, typically helping overcome knowledge or capability obstacles rather than trying to make and transfer completely new products or processes. *Second*, there is increasing convergence between technologies and scientific disciplines, which is giving rise to new scientific fields and the emergence of 'hyphen technologies' cutting across existing boundaries, leading to the increasingly systemic character of research. *Third*, globalisation is an important driver for change because science as such is global in nature, but also due to other reasons, such as collaboration and competition in science and innovation, access to global know-how, and global socio-economic challenges. *Fourth*, policy is an increasing driver for change, especially in relation to the European Research Area (ERA) because European research resources will need to be much more concentrated in the future. *Fifth*, the proportion of competitive funding in the funding structure of RTOs is increasing and their 'core' or basic funding is diminishing. These changes are both driven by a political desire to share the cost of public institutes with industry and by the growth in the use of ideas from the New Public Management movement.

The following trends among RTOs can be identified. *First*, they are focused more towards basic research, university links, and upskilling of their staff. The increasingly scientific basis of technology and the growing capabilities of customers are encouraging closer cooperation between institutes and universities, such as cross and joint appointments, Ph.D. student exchanges, and joint research projects. *Second*, the trend towards polytechnicity, the convergence of institutes' thematic specialisation, and the shift towards a wider range of disciplines, because customers' more difficult and complicated problems require cross-disciplinary solutions. *Third*, RTOs are continuously developing their organisation and scale, as they believe that they need to be polytechnic in order to service wide-ranging customer needs, and need to be big enough in each specialisation area to be attractive to customers and visible internationally. *Fourth*, RTOs are looking for ways to accelerate their internationalisation by finding new customers abroad and maintaining contacts with their internationalising domestic customers. In practice, traditional RTOs have not internationalised much. *Fifth*, RTOs are widening their missions and paying growing attention to markets and developing their various forms of commercialisation activities accordingly.

VTT is the only RTO in the Finnish innovation system

VTT plays an important role in Finland's national innovation system as the country's largest RTO and public research organisation (PRO). Although PROs make up a large part of research and innovation systems, they are not much discussed or studied internationally compared to universities. VTT differs from other PROs in several ways: It represents a wide range of scientific and technological expertise, while other PROs tend to be specialised in selected socio-economic and administrative sectors. The primary focus of VTT's research is in applied research, but VTT is also strong in academic research according to scientific indicators (biblio-

metrics, collaboration, etc.). VTT is also moving away from technology-driven programmes towards more broadly defined missions and global socio-economic challenges. VTT is in the same position as PROs in some governmental procedures and plans, however, as can be seen in the current plans to merge PROs in Finland into larger units.

VTT's basic mission, strategy, and organisational aspects are in line with those of other Finnish PROs and European RTOs. These are framed and articulated in the Act and Decree of VTT, and receive concrete form in the performance management procedures and annual performance contracts between the Ministry of Employment and the Economy (MEE) and VTT. VTT's roles are related to various dimensions, such as networking, coordination and combination of scientific expertise, involvement in different phases of innovation processes, accelerating the application of new technologies, and the future dimension of RTI development.

High quality is essential for credible R&D services, strategic research, and competencies

The high scientific quality of VTT's R&D and innovation services is an important criterion for the credibility of VTT's customer services and for government because basic funding is granted to VTT, not only for long-term strategic research, but also to develop the high-level scientific competences needed to offer qualified research services. In comparison with Finnish universities and PROs, VTT's research quality is among the highest nationally. In 2006–2008, for example, VTT scored fourth-highest in a citation index comparison among Finnish research organisations. Moreover, VTT's proportion of scientific publications placed in the top 10% of the world's most-cited publications and was the second-highest figure in the comparison. VTT has also benefited increasingly from domestic collaboration and even more from international collaboration in terms of citations. In addition, the share of joint publications co-authored with international partners has steadily increased (from 25% in 1990–1993 to 42% in 2006–2009). The bibliometric figures indicate that RTOs such as VTT can contribute to basic research even though their main role is in applied research.

Contract research the key channel in commercial research services

Knowledge transfer via the commercialisation of research results is among the key strategies of applied RTOs of the VTT type. For VTT, the most important channel for commercialising research results are contract R&D services (€80 million or 30% of turnover in 2012). VTT has roughly 1,500 clients, the majority of which are Finnish companies, but there is a clear trend towards acquiring more foreign clients (25% foreign companies in 2012). Around half of VTT's national and international private clients are SMEs at the moment. A second commercialisation channel runs via IPRs and their sale or licencing. VTT is among the most active Finnish players in patenting new technologies. VTT's annual IPR income has doubled

during the last five years (€2.1 million in 2012). A third channel for commercialising VTT's research runs via its feed into entrepreneurial activities. VTT subsidiary, VTT Ventures, uses technology and IPR created by VTT to set up spin-off companies and infuse these start-ups with complementary knowledge from its network of incubators, accelerators, mentors, trainers, and venture and angel capital players. VTT Ventures currently has invested in 23 companies, which have raised overall capital of €15 million.

Extension and diversification of internationalisation activities among key challenges

RTOs are part of the global scientific community and affected by and integrated with global scientific and technological development. Research collaboration through EU programmes accounts for the largest part of VTT's international activities and VTT had the largest funding share of Finnish research organisations in the EU's framework programmes in 2011. VTT has a very good European ranking (12th in 2011) in terms of attracting European project funding and it has a good networking activity and reputation (ranked 6th in 2011). VTT's revenue from overseas amounted to 18% of total revenue in 2011, of which 11% was EU programme project funding. VTT has the highest volume of foreign company funding of all Finnish PROs. VTT's impact on internationalisation occurs not only through direct RTI collaboration but also via transfer of acquired and absorbed knowledge in projects to Finnish clients, aimed at strengthening the international competitiveness of Finnish companies. VTT has also developed new forms of international activities such as Kemira Corporation's and VTT's joint R&D centre in São Paulo, Brazil and the Joint Institute for Innovation Policy (JIIP), a joint venture of VTT, TNO, Joanneum Research, and Tecnalía, which provides support to policy-making in research and innovation policy, especially for the EU.

8.2 Key results from quantitative and qualitative innovations analysis

Innovations are an important complementary indicator in impact assessment

The industrial, socio-economic, and ecological impact of research investments emerge via the innovation outputs of both existing and new companies and via changes in their subsequent performance and size. The knowledge generated can subsequently spill over via existing or new networks. Impact assessments are usually based on company-level (subjects) data collected via R&D surveys. Data on individual innovations ('objects') is typically missing from traditional impact analysis. Innovations can be considered as a conduit from the outputs of research funding to socio-economic and ecological impact, however, and as such are among the key indicators related to the impact that research funding has, complementing traditional indicators. VTT's SFINNO database provides an excellent

opportunity to analyse individual innovations, as it contains roughly 5,000 significant innovations commercialised by Finnish companies between 1945 and 2009. The SFINNO survey data can be used to assess VTT's role in and contribution to the development of Finnish corporate innovations.

VTT contributes to highly complex innovations, core technologies, and commercialisation

Analysis of the SFINNO database has provided us with a number of insights into VTT's role in nurturing Finnish innovations. First, it appears that VTT is an important collaboration partner for companies that have developed innovations and then launched them commercially. During 1985-2009, VTT collaborated in around 34% of all observed innovation projects, and this percentage remained stable over the entire period. In comparison to other types of potential partners for Finnish innovators, VTT is the second-most important innovation partner after all 10 domestic universities, as they are counted together. VTT also increasingly contributes to innovations that originate from its own in-house R&D, and has been responsible for almost 3% of Finnish innovations in recent times. As a collaborative partner and provider of expertise and know-how, VTT's role is considered especially important in the development of highly complex innovations, and VTT's significance is deemed higher in the context of developing more novel innovations. Another question that we looked at is the type of know-how behind innovations in which VTT played a role compared to innovations in which VTT had no part. It appears that a significant role was most typical in the context of developing companies' core technology and production methods, which are both considered strategically important. Given their small home market, exports are a crucial objective for Finnish innovators. Since 2005, innovations in which VTT has played a role have been slightly more frequently internationalized than those in which VTT did not take part.

VTT's diverse roles are highlighted in an analysis of individual innovations

Seven empirical case studies of industrial innovations involving a contribution from VTT help outline VTT's diverse roles during the various phases of Finnish companies' innovation processes. These cases exemplify the significance of focused long-term research in developing competencies that are critical to VTT's industrial customers' solutions. In order to bring added value to its industrial customers, VTT's commitment to strategic long-term research in scientific and technology areas relevant to future industrial development is crucial. The socio-economic and ecological impact of these long-term strategic commitments emerge after the commercialisation phase. Environmental or health benefits, for example, are the sum of various factors driven by marked demand or regulations, and it is often difficult to attribute final impact to one specific innovation.

8.3 Recommendations for further analysis of VTT's role and impact

In conclusion, the authors would like to propose the development of a strong impact assessment culture for VTT in the future. To fine-tune its performance in a fast-changing environment, VTT could benefit from recurring, wide-ranging impact studies, as they can offer a mirror for dynamic change. Better data and the use of multiple evaluation methods will be needed for this. Important topics that could feature in these VTT impact studies are as follows:

Many proposals for the further analysis of the links between VTT and universities and industries in innovation eco-systems emerged during this report. Further efforts aimed at developing more rigorous tests of the causal relationships between VTT's activities and observed outcomes and impact are needed. One conclusion of this study is that evaluation and impact assessment results are a sound basis for decision-making processes.

Many studies indicate that the mobility and circulation of staff between key organisations in the innovation eco-system, and the spill-over effects they create, are of key importance for successful innovation. Systematic data on the mobility of VTT's staff between industry, universities, policy organisations, and other bodies is scarce, however, both at national and international level, and this should be studied in more detail.

The understanding of the evolution of VTT's customer relationships represents an important source of knowledge for boosting VTT's R&D services. The long-term relationships between VTT and its customers could benefit from being investigated in more detail. The findings of broad-based customer analyses could make it easier and more effective to identify and source new clients for VTT.

A careful analysis of spin-offs could be warranted to compare VTT's spin-offs with those of Finnish universities and/or the spin-offs of other RTOs, such as Fraunhofer Gesellschaft, TNO, and the Austrian Institute of Technology (AIT).

Earlier evaluation studies have considered VTT's regional impact (e.g. Oksanen 2003). The SFINNO database offers a number of opportunities for a more detailed analysis of VTT's contribution to innovations in various Finnish regions. The study by Valovirta et al. (2009) already analysed SFINNO database innovation in Finnish regions and such analyses could concentrate on innovations involving a VTT contribution in the future.

The counterfactual analysis of RTOs is scarce and is seen as a challenging method. This approach could be considered for VTT by identifying an appropriate control group (countries with and without RTOs etc.), or, as referred to in the case of the OECD's report above, an alternative way of using the public investments that government grants to VTT.

The study also indicated that there is still relatively little assessment of the various roles, forms, and impact of VTT's internationalization, and this theme could feature on the impact assessment research agenda in the future (benefitting from earlier policy and research documents, e.g. the PROGLOBAL study of PROs

(Loikkanen et al. 2010). VTT's impact on internationalisation occurs not only through direct RTI collaboration but also via the transfer of acquired and absorbed knowledge in projects to Finnish clients, aimed at strengthening the international competitiveness of Finnish companies. We do not, however, have any comprehensive estimations of this impact, and it could be explored through interviews and customer survey investigations.

8.4 Towards broad-based monitoring of VTT's roles, effectiveness, and impact

This study considers various approaches and methodologies in analysing the effectiveness and impact of research in general and of RTOs in particular. It introduces the general framework of impact and effectiveness assessment and analyses multiple quantitative and qualitative methods to assess the impact of research, the different categories of impact, and the key challenges faced by impact analysis. The study also makes a general suggestion for a roadmap of future practices in impact assessment at VTT. The study concludes by proposing the launch of a new series of VTT impact studies to analyse the different aspects of VTT's impact on the Finnish economy and society. The series would benefit from the collection of better data and the use of the latest evaluation methods.

Epilogue

Private and public research and technology and innovation funding is under growing pressure, which is putting growing strains on RTOs and other public research organisations by assessing their performance, effectiveness, and impact. The question is whether, in today's world of global economic change, they will be able to retain their position in economic and innovation systems in the future on the basis of their traditional ability to adjust to changing environments. We may quote here the OECD study of 1989 on the changing role of government laboratories, which concluded in 1989: 'Government research establishments never die, they survive through various transformations while at the same time retaining a strong sense of tradition.'

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Case: ChemSheet technology, Prof. Pertti Koukkari, 19.12.2012.

Case: Integrated production of bio-oil: VTT Principal Scientist Jani Lehto, 17.12.2012.

Appendix 1: The economic and social impact of VTT according to the EARTO methodology

Box A.1 The economic and social impact of VTT according to the EARTO methodology

To demonstrate the nature of the roles of RTOs in Europe, the European Association for Research and Technology Organisations (EARTO) recently released a report that calculated impact figures based on all available European RTO data (EARTO 2011). Although the results should be interpreted with care, the overall robust message is that RTOs play a significant role in European innovation. In this general impact report, we deemed it informative to apply their approach to VTT. The simple impact model we follow here is based on the work of Oxford Economics for AIRTO in the UK. The model we apply considers the following four categories of impact:

- (1) Direct component, representing the contribution of VTT to Finnish GDP. This is the contribution to added value calculated by subtracting all input values such as wages, salaries, and profits from output values.
- (2) Indirect component, capturing the dependence of VTT on its suppliers and on the users of its outputs. This component is calculated based on the estimated flows of inputs and outputs.
- (3) Component that captures Keynesian-type multiplier effects. This component incorporates the fact that the expenditure of VTT and its employees stimulate activities in other areas of economic activity. This is the so-called 'induced impact' of VTT's activities.
- (4) Social returns on investment in R&D activities. This component comprises the private returns created for VTT and its clients and spill-overs to other sectors of the economy.

The table below shows the resulting estimates. Although they are subject to large uncertainties, they illustrate that VTT constitutes a force of considerable size in Finnish innovation.

Estimated economic impact of VTT	Million EURO
Direct	147,6
Indirect	130,9
Induced	+/- 55,7
Social returns	156
TOTAL	490,2 – 378,8

On the basis of the Oxford Economics methodology, therefore, the overall annual impact of VTT is estimated to be in the range of €379-490 million. The figures above ignore the long-term dynamic effects of R&D, however, as the social returns are estimated with a simple 1-year horizon. As returns on R&D usually extend well into the future, it is necessary to calculate social impact over a longer period. Using a standard discount rate of 3.5% over 10 years, the social impact of VTT is in the order of €1–1.5 billion. Much larger figures than the ones in the above table are also suggested by econometric work that analyses the relationship between R&D, productivity, and GDP. Guellec and van Pottelsberghe (2004) suggest that a 1% in business R&D increases national productivity/GDP by around 0.13%. Additional evidence from the U.S. leaves us with two important messages: (1) the average social return of privately financed R&D is two to three times higher than the average private return (65% versus 25%). (2) The returns of privately financed R&D are considerably higher than those of publicly financed R&D. (Sveikauskas 2007). However, the latter finding does not come as a surprise, as both types of R&D are supposed to be complementary.

Appendix 2: Empirical evidence on the various roles of VTT – Summary of the results from the VTT Sfinno project

This description is based on a conference paper by Konttinen, J., Hyytinen, K. & Hyvönen, J (2006): THE IMPACT OF PUBLIC RESEARCH ORGANISATION ON FIRM'S INNOVATION PROCESS. The Case of VTT presented at the INNOVATION PRESSURE International ProAct Conference 15–17th March 2006, Tampere, Finland.

VTT conducted a project in 2004 to study its role in the development processes of commercialised innovations. The objects of the study were eight industrial innovations that were developed in joint projects between VTT and its corporate partners. The aim was to deepen the understanding of the role of VTT in innovation processes, particular from the corporate standpoint. The data was collected through semi-structured interviews of corporate personnel. Interviewees were asked to characterise the innovation in question, identify VTT's role in the development process, and assess the impact of the innovation on their company's performance and to society as a whole. The case studies gave an insight into VTT's contribution in the different phases of innovation processes and provided empirical knowledge on the impact of VTT's contribution over the short and long term.

The point of departure was the Sfinno database on Finnish innovations. The definition of innovation in Sfinno relies loosely on the definition provide by the OECD in the Oslo Manual and has been defined as an invention that has been commercialised in the marketplace by a company. An innovation should also be a technologically new or a significantly enhanced product compared to a company's previous products. Innovations in the database have been identified from three different sources, namely from technical and trade journals, annual reports of large companies, and expert opinion panels.

The data from Sfinno that we used covered 1985–98 and included a total of 724 innovations. 129 of the respondents described cooperation with VTT as either significant or very significant during the development of their innovation. In the VTT Sfinno project, we used four criteria for selecting eight innovations: the year of commercialisation, the size of the company, the industrial sector, and the significance of the innovation. We decided that the year of commercialisation should not be later than 1995, mainly for practical reasons, e.g. people involved are easier to trace in these cases. We also wanted to ensure that small, medium-sized, and large firms are all represented in the case studies, as well as different industrial sectors. In the Sfinno data, electronics, metal products, chemicals, and machinery were sectors where the role of VTT was significant. In assessing the significance of innovations, we used one variable from the Sfinno database based on expert opinions.

Due to reasons of confidentiality, we cannot use the actual names of the innovations and companies in this context. A summary of the basic information on the companies interviewed is provided in Table 1.

Table 1. Summary of innovation profiles in the VTT Sfinno project.

Innovation	Year of commercialisation	Industrial sector of the innovation	Size of the company
1	1995	chemicals	large
2	1998	pulp & paper	medium
3	1993	instruments	small
4	1997	instruments	small
5	1997	metal	medium
6	1996	chemicals	large
7	1993	machinery	small
8	1992	chemicals	medium

In the case studies, the role of VTT in the innovation process varied from to basic testing services to participating in large technology research programmes. One obvious role for VTT was to increase the understanding of scientific phenomena. In these cases, cooperation started in the early phase of development, well before commercialisation. In one case, a deeper understanding of combustion emissions and temperatures was relevant for the further development of the fibre and to understand its physical limitations.

VTT was also a mediator in technology transfer. In one of the cases studied, the company developed and produced products that were based on casting. The company's strategy was to be a technology leader in the field. In order to stay at the forefront of technology, the company decided to add electronic elements to their products. This led to cooperation with VTT and electronics know-how was transferred to the company in a joint project that lasted two years. The electronic component for the product was successfully developed during the project and an electronics production line developed in the company. The company says that it wanted to cooperate with VTT as VTT had the competence in the application they needed and that VTT is closer to the application world and markets than universities. It was also relevant that VTT was a local actor, which made cooperation more intensive, easier, and more effective for the company. The company also preferred joint VTT-Tekes-company projects as they are economically feasible.

One issue that came up in the interviews was that after an idea for an innovation emerged in a company, researchers at VTT helped solve the practical problems. One of the interviewees emphasised that the biggest help provided by VTT

in the innovation process was that it could produce the appropriate technology that matched the processes and the machinery. Another successful factor in this case was that VTT and the company worked closely together throughout the process. According to the interviewee, cooperation works best when a company has the idea and the 'market hunch' and has close contacts with VTT's developers. Another interviewee, however, highlighted the fact that when a company interacts closely with VTT and its subcontractors, also involved in the development process, it is almost impossible to separate the role of VTT in the resulting process.

Another company emphasised VTT's role in refining ideas into a feasible concept. In this case, which was closely related to the previous case, the company had an initial idea for an innovation and VTT brainstormed its feasibility and refined the idea into a concept. The solution included the concept and the processes needed for manufacturing the end-products. According to the interviewee, VTT's advantage in this case was its application competence and know-how. State-of-the-art scientific knowledge was a necessity in this project, but when carrying out practical research, the interviewee considered that cooperation with universities would have been too academically oriented. Another interviewee also speculated that the major difference between VTT and universities was that VTT has more potential in carrying out a project with commercial goals than universities.

In some cases, VTT's role was emphasised in building networks. VTT was able to gather up the right competence from other companies for a development project that was originally initiated on a bilateral basis. According to an interviewee, one important factor was that VTT had connections with other companies operating in the same field, which made it possible to link competences and potential subcontractors to a project at an early phase. Another interviewee pointed out that VTT was able to skilfully integrate the research needs of the company with a Tekes technology programme and link the company to public financiers and other actors in the same field.

VTT's role has also been recognised in the later phase of the innovation process. According to interviewees, there were two different ways in supporting commercialisation. Firstly, VTT plays a role in handling tasks relating to technical inspection, such as testing, verification, and certification. VTT also serves as a 'notified body' in accordance with various EU directives, preparing certificates for customers' production, products, and services and ensuring that they are suitable for the intended markets, users, and the authorities. In some interviews, VTT's role in inspection has been mentioned as crucial in entering specific markets. In some cases, a research partnership with VTT was emphasised as a reference for market entry. One SME underlined that using cooperation with VTT as a marketing tool helped their product penetrate international markets.

Title	Roles, effectiveness, and impact of VTT Towards broad-based impact monitoring of a research and technology organisation
Author(s)	Torsti Loikkanen, Nina Rilla, Matthias Deschryvere, Janne Lehenkari, Juha Oksanen, Jukka Hyvönen, Robert van der Have & Erik Arnold
Abstract	<p>Research and technology organisations (RTOs) are key players in the national innovation systems of many industrialised countries and they act as an increasingly recognized knowledge pool in boosting innovation and economic development in the European Union. RTOs receive basic funding for their strategic long-term research and the development of scientific competence from government. They also receive state funds for joint research funded by national agencies and EU Framework Programmes, and obtain contract research income from private and public customers. All funding sources are under pressure due to changes in the national and global economic and innovation landscape and growing performance, effectiveness, and impact pressure on research, technology, and innovation (RTI). In this context, the aim of this study is to investigate the roles, legitimacy, and socio-economic impacts of VTT Technical Research Centre of Finland.</p> <p>This study has the following objectives: (1) To give a European and global perspective on the roles, rationale, and trends of RTOs, in order to out our analysis of VTT in perspective; (2) in the context of the Finnish innovation system, to explore the roles through which VTT enhances innovation performance and generates socio-economic and ecological impact; (3) to outline a toolbox of methodologies for exploring VTT's impact; (4) to carry out a quantitative analysis of innovations in the SFINNO database concerning VTT's contribution; (5) to carry out a case-study analysis of seven individual innovations involving a VTT contribution; and (6) to assess and make recommendations for topics and methodologies in VTT's impact studies in the future. VTT's roles and impact are considered in the context of major global socio-economic and technological challenges, and special attention has been paid to VTT's internationalisation and its roles in enhancing the innovation performance of small- and medium-sized companies.</p>
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Roles, effectiveness, and impact of VTT

Towards broad-based impact monitoring of a research and technology organisation

Research and technology organisations (RTOs) are key players in the national innovation systems of many industrialised countries and they act as an increasingly recognized knowledge pool in boosting innovation and economic development. This study investigates the roles, legitimacy, and socio-economic impacts of one of the largest RTOs in Europe, VTT Technical Research Centre of Finland.

In the context of the Finnish innovation system, the study explores the roles through which VTT enhances innovation performance and generates socio-economic and ecological impact. A quantitative analysis of VTT's contribution to the Finnish innovations is carried out by utilizing the unique SFINNO innovation database. This is supplemented by case studies of seven significant innovations involving a VTT contribution.

VTT's roles and impact are considered in the context of major global socio-economic and technological challenges, and special attention is paid to VTT's internationalisation and its roles in enhancing the innovation performance of small- and medium-sized companies.

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