Tekes

Tekes Programme Report 6/2010

Evaluation Report

# From Spearheads to Hunting

## Evaluation of Nano Programmes in Finland

Tuomas Raivio, Piia Pessala, Jatta Aho, Tiina Pursula, Alina Pathan, Jukka Teräs and Kaarle Hämeri

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**Tekes, the Finnish Funding Agency for Technology and Innovation**

Tekes is the main public funding organisation for research and development (R&D) in Finland. Tekes funds industrial projects as well as projects in research organisations, and especially promotes innovative, risk-intensive projects. Tekes offers partners from abroad a gateway to the key technology players in Finland.

**Tekes programmes – Tekes´ choices for the greatest impact of R&D funding**

Tekes uses programmes to allocate its financing, networking and expert services to areas that are important for business and society. Programmes are launched in areas of application and technology that are in line with the focus areas in Tekes' strategy. Tekes programmes have been contributing to changes in the Finnish innovation environment for twenty years.



ISSN 1797-7347
ISBN 978-952-457-510-2

Cover picture Kari Lehkonen
Page layout DTPage Oy

# Foreword

"There's plenty of room at the bottom" were the famous words of Richard Feynman in 1959. Since then, both nanoscience and nanotechnology have been developed steadily and gradually, especially in the United States. In the 1990s and 2000s a large number of nano R&D programmes were started in nearly all countries and the competition has increased substantially. The interdisciplinary nature of nanotechnology makes it possible to create applications in a wide set of areas and to gain a unique competitive advantage. Besides, the issue of nanosafety has become more important and the public debate has to be noted.

In Finland, the first nanotechnology programme was introduced in 1997. Later on, the FinnNano programme and Ministry of Education's nanoscience funding have multiplied the resources available. A large number of researchers and companies have taken part in these programmes. There are signs of exciting research breakthroughs and innovations.

When the FinnNano programme was coming to an end, Tekes together with the Academy of Finland and the Ministry of Education decided to evaluate all the Nano programmes. The main idea was to find out what should be the next steps in R&D and investment activities within the nanosector, how we could improve coordination and other activities between funding organisations and how the recommendations of research and innovation policy should be taken into consideration. The evaluation focused on the objectives, results and impacts of the programmes. The time span was more than 10 years, in order to tackle the long-term impacts.

The evaluation was carried out in good cooperation. The Ministry of Education, the Academy of Finland and Tekes were the commissioners, and the steering group consisted of their representatives: Erja Heikkinen, Markku Lämsä, Anssi Mälkki and Pekka Pesonen. The evaluation team consisted of the following experts: Tuomas Raivio, Alina Pathan, Piia Pessala, Tiina Pursula, Jatta Aho, Kaarle Hämeri and Jukka Teräs. We would like to thank all the evaluators for robust and insightful evaluation, the steering group members for their commitment in utilisation of the results and all those who participated for their valuable contribution. This report has been titled From Spearheads to Hunting, following the strategic guidelines in 2005 (Nanoscience spearheads in Finland). Now it is time to hunt.

September 2010

The Academy of Finland, the Ministry of Education and Culture,
Tekes, the Finnish Funding Agency for Technology and Innovation

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# Abstract

This evaluation deals with the field of nanoscience and technology in Finland. The main emphasis has been on the evaluation of four programmes: Nanotechnology, funded jointly by Tekes and the Academy of Finland in 1997–1999; Tekes' FinNano (2005–2010); the Academy of Finland's FinNano (2006–2010) and the Ministry of Education and Culture's funding for nanoscience (2007–2009). To support the evaluation, Finnish nanoscience and nanotechnology and business fields as well as the political, economical and social aspects in the society have been described.

The evaluation was based on document analysis, interviews, micro cluster analysis and workshop activities. In the micro cluster analysis, thematically representative or otherwise interesting samples from programme projects were selected, and in-depth interviews were carried out with the project managers. The analysis provides an in-depth picture of the developments in the programme and its impacts, but it must be borne in mind that the result is a qualitative study. The analysis was supported by other interviews and document analysis.

In the light of the analysis, all the programmes have succeeded well. The early Nanotechnology programme was a nano catch-up programme that increased Finnish knowledge about nanoscience and technology by bringing together different disciplines under a common technological and scientific denominator. The FinNano programmes of Tekes and the Academy of Finland have boosted Finnish nano research and business, and the Ministry of Education's nanoscience funding has provided partial funding for research infrastructures. Cooperation between the programmes mainly took place behind the scenes, but it was essential to prevent overlaps and to increase the coherence of funding.

As a slight downside to each programme, it may be mentioned that the Nanotechnology programme was a "catch-up" type . Tekes' FinNano did have large company coverage, but it was mainly through the joint funding of research projects; the Academy of Finland's FinNano programme seem to have suffered slightly from the fragmented nature of funding, and the Ministry of Education's nanoscience funding was technically problematic since the funds had to go through the universities .

In the analysis, several development points concerning the nano sector were identified that cannot be affected by programmes. Furthermore, nano as the common denominator is losing its significance. Therefore, subsequent developmental steps should be implemented by other means, such as technology transfer, encouragement of entrepreneurship, increased seed funding, and basic research funding focusing on problems and challenges rather than on disciplines.

# Tiivistelmä

## Johdanto

Nanoteknologia tarjoaa uudenlaisia mahdollisuuksia kehittää tuotteita ja niiden ominaisuuksia. Nanoteknologialla uskotaan olevan huomattava yhteiskunnallinen vaikutus tulevaisuudessa. Sen avulla voidaan valmistaa yhä pienempiä ja tehokkaampia elektroniikkalaitteita ja uudenlaisia materiaaleja. Nanoteknologian uskotaan myös avaavan uusia ovia energiantuotannon ja lääketieteen aloilla. Suomi on monien muiden maiden tavoin tunnistanut nanoteknologian mahdollisuudet. Kehitys nanosektorilla etenee yritysten ja tutkimuslaitosten yhteistyönä. Suomalainen innovaatiojärjestelmä edistää tehokkaasti tutkimustulosten soveltamista käytäntöön.

Tässä raportissa arvioidaan neljää suomalaista nano-ohjelmaa ja niiden tuloksia. Arvioitavat ohjelmat ovat Tekesin ja Suomen Akatemian Nanoteknologian tutkimusohjelma (1997–1999),Tekesin FinNano-ohjelma (2005–2010), Suomen Akatemian Nanotieteen tutkimusohjelma FinNano (2006–2010) sekä opetus- ja kulttuuriministeriön Nanotieteen hankerahoitus (2007–2009). Arvioinnissa keskitytään ohjelmien tavoitteisiin, tuloksiin ja vaikutuksiin. Myös ohjelmien kontekstia sekä sidosryhmien välistä yhteistyötä ja tiedonjakoa arvioidaan.

Arvioinnin tilasivat Tekes (*Teknologian ja innovaatioiden kehittämiskeskus*), Suomen Akatemia sekä opetus- ja kulttuuriministeriö. Arviointi tehtiin ohjausryhmän valvonnassa. Ohjausryhmään kuuluivat Pekka Pesonen (Tekes), Markku Lämsä (Tekes), Erja Heikkinen (opetus- ja kulttuuriministeriö) sekä Anssi Mälkki (Suomen Akatemia).

Arvioinnin suoritti Gaia Consulting Oy:n johtama asiantuntijaryhmä, johon kuuluivat Gaia Consulting Oy:stä Tuomas Raivio, Alina Pathan, Piia Pessala, Tiina Pursula ja Jatta Aho. Konsortioon kuuluivat lisäksi prof. Kaarle Hämeri (Helsingin yliopisto/Työterveyslaitos) sekä TkT Jukka Teräs (Norrum Oy).

## Metodologia

Arvioinnissa käytetyn aineiston keruu sekä analysointi toteutettiin käyttämällä seuraavassa kuvattuja menetelmiä.

### A. Kirjallisen materiaalin analysointi

Osana arviointia analysoitiin nano-ohjelmien valmisteluraportteja, loppuraportteja, arviointiraportteja sekä rahoitushakemuksia.

### B. Taustahaastattelut

Analyysin tueksi suoritettiin 10 taustahaastattelua. Ne kohdistettiin henkilöihin, jotka olivat perehtyneet nanoteknologiaan sekä olleet suunnittelemassa ja/tai toteuttamassa nano-ohjelmia ja/tai nanotieteisiin liittyviä projekteja. Haastateltavat henkilöt valittiin yhdessä arviointihankkeen ohjausryhmän kanssa.

### C. Sidosryhmähaastattelut

Sidosryhmähaastattelujen avulla muodostettiin kokonaiskuva nanosektorista sekä nano-ohjelmien onnistumisesta ja vaikutuksista. Haastateltavat henkilöt valittiin yhdessä arviointihankkeen ohjausryhmän kanssa. Yhteensä 10 sidosryhmien edustajaa haastateltiin. Nämä henkilöt edustivat mm. yrityksiä, yliopistoja ja tutkimuslaitoksia.

### D. Mikroklusterianalyysi

Syvällisempi ohjelma- sekä rahoitusyhteistyöanalyysi tehtiin hyödyntäen valikoituja mikroklustereita. Arviointiryhmän aiemmin tekemän aineistoanalyysin perusteella nano-ohjelmista poimittiin seitsemän temaattisesti yhtenäistä tai muulla tavoin samankaltaista projektiryhmää – mikroklusteria, joiden vastuuhenkilöt haastateltiin.

Tämän menetelmän arvioitiin luovan syvällisemmän läpileikkauksen nano-ohjelmista kuin jos olisi vertailtu yksittäisiä nano-ohjelmilla rahoitettujen projektien tuloksia ja vaikutuksia. Johtuen ohjelmien sisällöllisestä vaihtelevuudesta, eroavat tässä arvioinnissa esiintyvät mikroklusterit ja niiden rakenne kuitenkin paikoitellen keskenään paljon.

Arviointihankkeen ohjausryhmä päätti mikroklustereiden jaottelusta ja aihealueista. Yksi mikroklusteri koski Suomen Akatemian Nanoteknologian tutkimusohjelmaa, kaksi Tekesin FinNano-ohjelmaa, yksi Suomen Akatemian FinNano-ohjelmaa, yksi opetus- ja kulttuuriministeriön Nanotieteen hankerahoitusta, yksi innovaatiotoiminnan arvoketjunäkökulmaa ja yksi nanosektorin rahoitusyhteistyötä. Innovaatiotoiminnan arvoketju -mikroklusteri kuvasi Suomessa kehitettyä Nanohybtoniitin[1] innovaatiopolkua. Mikroklusterianalyysin aikana haastateltiin tai oltiin muulla tavoin yhteydessä kaikkiaan lähes 40 henkilöön.

**E. Työpaja**

Arviointityön viimeisessä vaiheessa järjestettiin työpaja, johon osallistui 11 arviointiprosessissa aiemmin mukana ollutta henkilöä. Työpajan tavoitteena oli vahvistaa ja jalostaa alustavia arviointituloksia. Lisäksi ideoitiin ja keskusteltiin Suomen nanoteknologian tutkimus-, kehitys- ja innovaatiotyön (t&k&i) kehitysnäkökulmista.

## Arviointikysymykset

Nano-ohjelmia arvioitiin seuraavien arviointikysymysten perusteella:

### Nano-ohjelmien tavoitteet ja tulokset

1. Kuinka relevantit ja haastavat tavoitteet ohjelmalle oli asetettu? Kuinka hyvin ne vastasivat kansallista strategiaa tällä sektorilla?
2. Kuinka hyvin asetetut tavoitteet toteutuivat? Saavutettiinko tavoitteiden mukaisten tulosten lisäksi muita tuloksia, jotka tukevat alkuperäisiä tavoitteita (tapausesimerkkejä)?
3. Millaisia alkuperäisistä tavoitteista poikkeavia tuloksia saavutettiin? Mitä näistä tuloksista ei olisi saavutettu ilman kyseessä olevaa ohjelmaa?
4. Kuinka hyvin ohjelmat tavoittivat tärkeimmät asiakkaat?
5. Kuinka hyvin ohjelmat sekä niiden palvelut ja johto vastasivat sidosryhmien tarpeisiin? Erityisesti, kuinka kansainvälinen ohjelmien välinen yhteistyö on vaikuttanut osallistujiin ja asiakkaisiin?

### Nano-ohjelmien vaikutukset ja toimintaympäristö

1. Mitä vaikutuksia ohjelman avulla on saavutettu tai odotetaan saavutettavan? Kuinka laajoina, pysyvinä ja tärkeinä nämä vaikutukset nähdään?
2. Kuinka, ja missä laajuudessa ohjelmilla on ollut vaikutusta
   - nanosektorin t&k&i-investointeihin?
   - tietotaidon lisääntymiseen, tutkimustyön kehittymiseen ja osaamiskeskuksien muodostumiseen?
   - asiantuntemuksen laajentumiseen nanosektorin sisällä?
   - kansallisten ja kansainvälisten verkostojen syntymiseen?
   - tärkeiden innovaatioiden ja liiketoimintamahdollisuuksien syntymiseen?
   - nanoteknologian maineeseen sekä aiheeseen liittyvän keskustelun syntymiseen ja ihmisten asenteisiin?
   - liiketoimintaan ja yhteiskuntaan laajemmassa mittakaavassa?
3. Mikä vaikutus rahoittajien yhteistyöllä (aikataulut, koordinointi) on ollut ohjelman tuloksellisuuteen ja vaikuttavuuteen?

Yllä esitettyjen arviointikysymysten lisäksi esitetään johtopäätökset ja suositukset seuraaviin kolmeen aihealueeseen liittyen:

***A. Nanosektorin t&k&i-toiminta:***

Kuinka t&k&i-toimintaa voidaan kehittää? Mikä on Strategisen huippuosaamisen keskittymien (SHOK) ja Osaamiskeskusohjelmien (OSKE) rooli tulevaisuudessa? Mitkä kansainväliset ohjelmat ja hankkeet ovat nanosektorille tärkeimpiä ja kuinka näihin voidaan vaikuttaa paremmin?

***B. Rahoittajat:***

Mitä konkreettista ja työskentelytapoihin liittyvää voidaan tunnistaa ohjelmien palveluiden ja toimintojen kehittämiseksi? Mitä suosituksia voidaan antaa rahoitusyhteistyön ja muiden rahoitustoimintojen kehittämiseksi (Tekes, Suomen Akatemia, opetus- ja kulttuuriministeriö)?

***C. Tutkimus- ja innovaatiopolitiikka:***

Miten kansallista innovaatiostrategiaa ja innovaatioympäristöä koskevat suositukset, jotka arvioinnissa esitetään, tulisi ottaa huomioon? Mitä muita toimenpiteitä tutkimus- ja innovaatiopolitiikassa tarvitaan, jotta rahoittajien toimintaa ja vaikuttavuutta voidaan parantaa?

[1] Hybtonite on tuotenimi hiilinanoputkivahvisteiselle epoksille.

## Arvioinnin kohteet

### Tekes & Suomen Akatemia: Nanoteknologian tutkimusohjelma

Tekesin ja Suomen Akatemian Nanoteknologian tutkimusohjelma toteutettiin vuosina 1997–1999. Kyseessä oli ensimmäinen Tekesin ja Suomen Akatemian yhdessä suunnittelema ja rahoittama ohjelma. Ohjelmaa rahoitettiin yhteensä 43,9 miljoonalla markalla, josta Suomen Akatemian osuus oli 18,3 miljoonaa ja Tekesin 25,6 miljoonaa markkaa. Ohjelmassa rahoitettiin yhteensä 14 projektia. Teollisuuden rahoitus oli vähäistä, eikä se ollut osallistumisen edellytyksenä.

Ohjelman tavoitteet määriteltiin yleisellä tasolla ja seuraavat trendit tunnistettiin:

- voimakas ja nopeasti kasvava kansainvälinen kiinnostus nanoteknologiaa kohtaan
- nanoteknologian valtava teollinen potentiaali
- tarve kouluttaa tutkijoita, joilla on uusia ideoita nanoteknologiapotentiaalin hyödyntämiseksi Suomessa
- tarve kasvattaa tutkijoiden kompetenssia nanosektorilla sekä tähän liittyvillä tieteenaloilla
- halu kiihdyttää uudenlaista monitieteellistä tiedonvaihtoa, joka johtaa odottamattomiin mahdollisuuksiin luovuuden ja innovaatioiden saralla
- tarve täyttää aukko nk. perustutkimuksen (normaalisti Akatemian rahoittamaa) ja soveltavan tutkimuksen (normaalisti Tekesin rahoittamaa) välillä sekä löytää keinoja lisätä näiden kahden organisaation yhteistyötä.

Ohjelmassa esitetyt sisällöt jaettiin viiteen luokkaan:

1. Nanobiologia
2. Itseorganisoituvat rakenteet
3. Toiminnalliset nanopartikkelit
4. Nanoelektroniikka
5. Informaatioteknologian biomateriaalit.

### Tekes: FinNano-ohjelma

Tekesin FinNano-ohjelmassa tutkittiin, sovellettiin ja kaupallistettiin nanomittakaavan järjestelmiä ja ilmiöitä. Ohjelman tavoite oli vahvistaa suomalaisen nanoteknologian tutkimusta valituilla alueilla ja kiihdyttää nanoteknologian kaupallistumisastetta Suomessa. Ohjelmassa painotettiin tutkimustulosten tehokasta hyödyntämistä sekä tutkimuslaitosten ja teollisuuden välistä yhteistyötä. Täsmennetyt tavoitteet olivat:

1. Vahvistetaan olemassa olevaa suomalaista tutkimusta ja tutkimuksen mahdollisuuksia sekä lisätään monitieteellisten tutkimusryhmien ja kehittämiskeskuksien kilpailukykyä.
2. Tehostetaan nanoliiketoimintaa tuotteistamalla lupaavat tutkimustulokset sekä vahvistetaan ja lukitaan nanoteknologian kaupallinen kehittyminen.
3. Tuetaan kansallista ja kansainvälistä verkostoitumista sekä tutkijoiden liikkuvuutta.
4. Edistetään suomalaisten tutkijoiden, tutkimuslaitosten sekä yritysten osallistumista EU:n nanoteknologiaohjelmiin.
5. Vahvistetaan alueellisia osaamiskeskuksia ja integroidaan nämä kansainväliseen toimintaan.
6. Edistetään tehokkuutta ja synergiaa resurssien ja infrastruktuurin käytössä.
7. Rohkaistaan yrityksiä tunnistamaan nanoteknologian mahdollisuudet ja luodaan yrityksille hyvät lähtökohdat hyödyntää nanoteknologiasovelluksia.

Ohjelmassa keskityttiin erityisesti

**A.** Innovatiivisiin nanorakenteisiin ja -materiaaleihin

**B.** Nanosensoreihin ja -toimilaitteisiin

**C.** Nanoelektroniikan uusiin ratkaisuihin.

Ohjelman projektisalkku sisälsi yli 100 tutkimukseen ja teollisuussovelluksiin liittyvää teknologiakehitysprojektia. Tutkimusta johdettiin korkeatasoisen konsortion toimesta. Konsortion kanssa yhteistyössä toimi kansainvälisiä tutkimusorganisaatioita sekä teollisuuden yrityksiä. Ohjelmaan osallistui noin 170 yritystä, joilla oli meneillään joko oma nanoteknologian kehityshanke tai vaihtoehtoisesti yritys rahoitti jotakin ulkopuolista tutkimushanketta.

Ohjelman volyymi oli noin 70 miljoonaa euroa, josta Tekesin rahoitusosuus oli 47 miljoonaa euroa. Ohjelma kesti hallinnollisesti yhteensä viisi vuotta 2005–2009, mutta suuri osa ohjelman projekteista on edelleen käynnissä. Ohjelma toteutettiin tiiviissä yhteistyössä Suomen Akatemian Nanotieteen tutkimusohjelma FinNanon kanssa.

### Suomen Akatemia: Nanotieteen tutkimusohjelma FinNano

Suomen Akatemian Nanotieteen tutkimusohjelman (Akatemian FinNano) painopiste oli monitieteellisessä nanotieteen tutkimuksessa. Ohjelma yhdisti nanotutkimuksen kemiaan, fysiikkaan ja biotieteisiin ja sen oli määrä tukea sektorin kokonaiskehitystä Suomessa. Ohjelman tematiikka keskittyi aihealueisiin, joissa perustutkimuksen tukeminen nähtiin erittäin potentiaaliseksi innovatiivisen tutkimuksen, kestävän kehityksen ja teollisen kilpailukyvyn kannalta.

Ohjelman tavoitteet olivat:

1. Tuetaan korkeatasoista nanotieteen perustutkimusta osana innovaatioympäristöä.
2. Aktivoidaan nanosektorin moni- ja poikkitieteellinen lähestymistapa.
3. Luodaan ohjelmaan osallistuville tutkimusryhmille konkreettista lisäarvoa verkostoitumisen, kansainvälisen näkyvyyden ja tutkimustulosten hyödynnettävyyden kautta.
4. Edistetään nanoteknologian vastuullista kehittämistä – tutkimusohjelmassa huomioidaan eettiset haasteet, so. turvallisuus-, terveys- ja ympäristökysymykset.
5. Edistetään Eurooppalaista sekä muuta kansainvälistä toimintaa ja tiedonvaihtoa nanosektorilla.

Ohjelma koostui 10 suomalaisesta konsortioprojektista, joita rahoitettiin vuosina 2006–2010. Lisäksi viittä hanketta (yhteistyö Suomi-Eurooppa ja Suomi-Venäjä) rahoitettiin kansainvälisten yhteistyötahojen kanssa. Projektit saivat kotimaista rahoitusta yhteensä 9,45 miljoonaa euroa.

Akatemian FinNano toteutettiin tiiviissä yhteistyössä Tekesin FinNano-ohjelman kanssa. Ohjelmia suunniteltiin yhdessä ja niillä oli useita yhteisiä toimintoja, kuten seminaareja ja tiedonjakoa.

## Opetusministeriö: Nanotieteen hankerahoitus

Opetusministeriö (OPM) rahoitti suomalaista nanosektoria yhteensä 19 miljoonalla eurolla vuosina 2007–2009. OPM:n Nanotieteen hankerahoituksen puitteissa ei rahoitettu yksittäisiä projekteja, vaan kyseessä oli pikemminkin valtion tuki yliopistojen nanotieteisiin liittyvälle toiminnalle. OPM:n nanotieteiden rahoitus oli osa rahoitusohjelmaa, jolla OPM pyrki tehostamaan tiettyjen tieteenalojen harjoittamista ja prosessien toimintaa. OPM nimitti työryhmän käymään läpi suomalaista nanotieteen tutkimustoimintaa ja antamaan suositukset nanotieteiden kehitysohjelmaksi. Tuloksena tunnistettiin kolme tärkeintä nanotieteen osa-aluetta, joita ehdotettiin pääaihealueiksi hankerahoitusta silmällä pitäen.

Perustuen OPM:n työryhmän suosituksiin tärkeimmiksi tavoitteiksi hankerahoituksessa nimettiin seuraavat asiat:

1. Vahvistetaan tutkimusedellytyksiä etenkin kolmen tunnistetun osa-alueen osalta (nanomateriaalit, nanoelektroniikka sekä -fotoniikka ja nanobioteknologia).
2. Tehostetaan sektorin sisäistä yhteistyötä ja koordinointia, pyritään lisäksi yhdistämään olemassa olevia tietoklustereita, infrastruktuuria sekä opetusta.
3. Tehostetaan nanosektorin tiedonvaihtoa sekä tutkimustulosten kaupallista hyödyntämistä.

Työssä huomioitiin myös että panostuksen tuli edistää molempien käynnissä olevien FinNano-ohjelmien tavoitteiden toteutumista. Rahoituksen voitiin nähdä suuntautuvan pääosin nanosektorin infrastruktuurin tehostamiseen, sillä esimerkiksi Tekes ja Suomen Akatemia eivät rahoittaneet tätä osa-aluetta.

Ohjelman hakemus- ja määrärahakäytännöt erosivat muista suomalaisista ohjelmapohjaisista rahoitusinstrumenteista, sillä rahoitus oli osa yliopistojen rahoitusmallia. Näin ollen rahoituksen hakijat olivat yliopistoja, eivätkä yksittäisiä tutkijoita tai tutkimusryhmiä. OPM arvioi hakemukset ja rahoituspäätökset tehtiin vuonna 2006.

Nanotieteen rahoitusta myönnettiin yhteensä kuudelle suomalaiselle yliopistolle. Rahoitusta saivat Tampereen teknillinen yliopisto, Jyväskylän yliopisto, Joensuun yliopisto[2], Helsingin yliopisto, Teknillinen korkeakoulu sekä

**Taulukko 1. OPM:n nanotieteiden rahoitus vuosina 2007–2009.**

| Yliopisto | Vuosi | | | Yhteensä |
|---|---|---|---|---|
| | 2007 | 2008 | 2009 | |
| Helsingin yliopisto | 1 500 | 1 500 | 1 000 | 4 000 |
| Jyväskylän yliopisto | 1 500 | 1 500 | 1 750 | 4 750 |
| Oulun yliopisto | 200 | 200 | 200 | 600 |
| Joensuun yliopisto | 800 | 300 | 300 | 1 400 |
| Teknillinen korkeakoulu | 2 540 | 1 500 | 1 500 | 5 540 |
| Tampereen teknillinen yliopisto | 1 000 | 1 000 | 1 000 | 3 000 |
| **Yhteensä** | **7 040** | **5 500** | **5 750** | **19 290** |

[2] Arvioinnissa on käytetty toteutusajankohdan mukaisia toimijoiden nimiä

Oulun yliopisto (ks. taulukko 1). Hakemus sisälsi suunnitelman siitä miten yliopistot aikovat käyttää myönnetyn määrärahan (esim. laitteistojen hankinta, palkka, koulutus ja matkustaminen). OPM painotti rahoituksessa nanosektorin infrastruktuurin kehittämistä. Yliopistot saivat kuitenkin käyttää omaa autonomista päätäntävaltaansa sen suhteen, mihin toimintoihin rahoitus yliopiston sisällä suunnattiin.

### Rahoittajien yhteistyö

Alun alkaen yhdeksi tärkeäksi tavoitteeksi oli asetettu yhteistyö Tekesin, Suomen Akatemian ja opetusministeriön kesken (FinNano-ohjelmat ja Nanotieteen hankerahoitus). Lähtökohtana yhteistyölle oli, että ohjelmat rakennetaan ja toteutetaan siten että ne täydentävät ja tukevat toisiaan.

Ensimmäiseksi nano-ohjelman käynnisti Tekes. OPM ei osallistunut tämän ohjelman valmisteluun mutta otti myöhemmin osaa mm. Tekesin ohjelman aikana järjestämään työpajaan. OPM ja Akatemia toimivat yhteistyössä jo rahoitusohjelmien käynnistämisvaiheessa. Tavoitteena olikin, että Akatemian Nanotieteen tutkimusohjelma ja OPM:n Nanotieteen hankerahoitus käynnistyisivät samaan aikaan. Lopulta kuitenkin Akatemian ohjelma käynnistyi hiukan myöhemmin.

Sekä Tekesin että Akatemian edustajia kuului OPM:n nimittämään työryhmään, joka analysoi nanotieteen aihealueita ja lopulta valitsi tärkeimmät osa-alueet, joihin päätettiin panostaa enemmän. Tekes ja Akatemia olivat myös mukana arvioimassa yliopistojen hakemuksia, jotka OPM oli vastaanottanut ennen hankerahoituksen käynnistämistä. Valittujen yliopistojen hakemukset olivat yhdenmukaiset työryhmän asettamien tavoitteiden kanssa ja lisäksi linjassa OPM:n, Tekesin ja Akatemian ohjelmien kanssa. Tärkeintä oli, että ohjelmien välillä ei syntyisi tahattomia päällekkäisyyksiä ja samalla päätökset tukisivat kaikkia kolmea ohjelmaa ja niiden tavoitteita. Toimintaa pyrittiin tehostamaan siten, että samoja ihmisiä vaikutti eri ohjelmien ohjausryhmissä.

Yhteistyö Tekesin ja Akatemian ohjelmien välillä oli tiivistä, kun taas yhteistyö OPM:n kanssa oli voimakkaimmillaan päätöksentekovaiheessa ennen rahoituskautta 2007–2009. Tekes ja Akatemia järjestivät yhteisiä keskustelufoorumeja ja muita tapahtumia. Useat tutkijaryhmät osallistuivat Tekesin ja Akatemian ohjelmiin ja tieto käynnissä olevista projekteista kulkeutui tehokkaasti ohjelmien välillä. Käytännössä yhteistyö Tekesin ja Akatemian välillä oli voimakkainta vaiheessa, jossa rahoitushakemuksia arvioitiin. Yhteistyö oli kaikista läpinäkyvintä ohjelmien vastuuhenkilöille mutta ei vaikuttanut aina kovinkaan vahvasti ohjelmiin osallistuviin tahoihin.

## Keskeiset tulokset

### Ohjelmien arviointi

#### Nanoteknologian tutkimusohjelma

Vaikka ohjelma oli kooltaan pieni, toimi se lähtöalustana suomalaiselle nanoteknologian tutkimukselle ja liiketoiminnalle. Ohjelman tavoitteena oli lisätä tietämystä ja tutkimuspotentiaalia nanosektorilla. Arviointimateriaalin perusteella voidaan todeta, että tavoitteet hyvin pitkälti saavutettiin. Vaikka joitain ohjelman aiheista oli jo tutkittu, vahvisti ohjelma nano-käsitettä ja samalla nanotietämys kasvoi.

1980- ja 1990-luvuilla Tekes toteutti useita samankaltaisia ohjelmia eri aihealueilla, esimerkiksi elektroniikka- ja automaatioaloilla. Varmasti osittain tämänkin ohjelman avulla Suomi sai kurottua eroa kiinni kyseisen sektorin edelläkävijämaihin. Näiden ohjelmien ajurina oli muualla tapahtuva kehitys ja eron kiinni kurominen. Ohjelman avulla Suomi on kasvatti merkittävästi nanoteknologista osaamista. Nykyiset yritykset, ja tutkimusryhmät juontavat juurensa osin tämän ohjelman ajoilta.

Ohjelman arviointiraportti julkaistiin vuonna 2000. Arvioijat totesivat ohjelman rakenteen ja hallinnoinnin korkeatasoisiksi. Erityisesti joustavuus teollisuusrahoituksessa sekä organisaatioiden ja johdon toiminnassa nähtiin innovatiivisen ja innostavan tutkimusilmapiirin päätekijäksi ohjelman aikana. Lisäksi Tekesin ja Akatemian yhteisrahoituksen luoma mahdollisuus tehdä monitieteellistä tutkimusta perustutkimuksen lisäksi nähtiin erittäin tärkeänä asiana. Ohjelmapalveluja ja kansainvälistä yhteistyötä ei arvioitu.

#### Tekesin FinNano-ohjelma

Toisin kuin Nanoteknologian tutkimusohjelma, Tekesin FinNano-ohjelma käynnistyi kun innovaatiopolitiikka oli tullut teknologiapolitiikan tilalle. Ohjelmien teknologiset tavoitteet korvattiin erinäisin tavoittein, jotka vaihtelivat teknologian ja tutkimuksen sekä kaupallistamisen ja liiketoimintamahdollisuuksien välillä.

Ohjelman tavoitteet on muotoiltu siten, että on hankala sanoa kuinka hyvin tavoitteet lopulta saavutettiin. On selvää että Tekesin FinNano-ohjelma on ollut tärkeä asia suomalaiselle nanoteknologian liiketoiminnalle ja tutkimukselle. Se on vahvistanut alan tutkimusta ja tehostanut kaupallistumista. Ohjelman pitkän aikavälin kansainvälistymistoiminnot sekä integroituminen EU:n toimintaan arvioidaan onnistuneen hyvin, mutta tutkijoiden liikkuvuuteen liittyen lopputulos on ollut vaatimaton. Tämä ei ole kuitenkaan pelkästään tämän ohjelman puute; monissa muissa arvioinneissa on kiinnitetty huomiota siihen, että kansainvälistyminen ja tutkijoiden liikkuvuus ovat kaikkiaan hankalia asioita Suomessa.

Tavoitteiden saavuttamisen kannalta selkeä ongelma on se, miten saada yritykset näkemään nanoteknologian mahdollisuudet. Tällä hetkellä moni yritys ei tunnista nanotuotteiden mahdollisuuksia. Jotkin yrityksistä myös ilmeisesti arvioivat nanotuotteiden tai -teknologian käyttöönottoon liittyvät riskit suuriksi. On selvää että ohjelma, joka on saattanut yhteen pelkästään nanosektorin yrityksiä, ei pysty yksinään ratkaisemaan tätä ongelmaa. Tämä on laajassa mittakaavassa kuitenkin suuri este nanoteknologian kaupallistumiselle ja siksi innovaatiopolitiikan saralla tulisi ryhtyä laajempiin toimiin tämän ongelman ratkaisemiseksi.

Ohjelman kattavuus oli hyvä – yhteensä yli 100 yritystä osallistui sen toteutukseen. Tämä on noin puolet kaikista Suomessa toimivista nanosektorin yrityksistä. Tästä huolimatta yritysrahoitus oli ohjelmassa melko vaatimatonta ja suurimmaksi osaksi tutkimusprojekteille suunnattua yhteisrahoitusta. Sekä suuret- että pk-yrityksiä osallistui ohjelmaan.

Ohjelman aikaiset palvelut olivat osallistujien mukaan onnistuneita. Etenkin useat pitkäjaksoiset matkat Kiinaan nähtiin tuloksellisena tapana synnyttää uusia kaupallisia kanavia. Toisaalta ohjelman aikaiset verkostoitumiseen suuntautuneet palvelut koettiin myös jossain määrin kyseenalaisiksi, sillä joidenkin mielipiteiden mukaan pk-yritykset ovat jo verkostoituneet vahvasti Nano-OSKE:n ja suuryritykset SHOK:ien kautta. On kuitenkin huomattava, sekä nano-OSKEn että SHOKien tuntemus oli mikroklusterihaastattelujen mukaan olematonta.

Ohjelman tärkein tulos lienee osallistujien välisten keskinäisten suhteiden vahvistuminen ja alan klusteroituminen. Joitakin uusia liiketoimintamahdollisuuksia synnytettiin ja myös uusia tutkimusaiheita tunnistettiin. Ohjelman tärkein lisäarvo syntyi kuitenkin rahoituksesta, verkostojen luomisesta sekä uusien yhteistyötahojen löytämisestä. Tässä mielessä FinNano-ohjelma on hyvä esimerkki tyypillisestä ja onnistuneesta Tekesin teknologiaohjelmasta.

### Suomen Akatemian FinNano-ohjelma

Suomen Akatemian FinNano-ohjelma oli suomalaiselle nanotutkimukselle jopa keskeisempi rahoituksen lähde kuin Tekesin FinNano-ohjelma yrityksille. Ohjelmassa verkostoitumistoimintojen ja muiden ohjelmapalveluiden rooli on pidetty melko pienenä. Oletuksena oli että tahot, jotka saavat Akatemian rahoitusta ovat jo verkostoituneet omalla sektorillaan eivätkä siis tarvitse enää apua tässä. Ohjelman menestymisen avaimet juontavat täten juurensa valintaprosessista ja siitä, mitkä tahot ohjelmaan valitaan.

Ohjelman tavoitteet oli asetettu melko yleispiirteisesti, joten tavoitteiden toteutumista ei ole järkevää arvioida yksityiskohtaisesti. Itse asiassa suurin osa tavoitteista täytettiin jo tieteellisen valintaprosessin aikana. Jotkin tavoitteista, kuten syventävän poikkitieteellisen lähestymistavan löytäminen, kestävän nanoteknologiakehityksen edistäminen sekä kansainvälisen yhteistyön lisääminen ovat vaatineet strategisia valintoja, kun projekteja on valikoitu mukaan ohjelmaan.

Akatemian rahoitus on arvostettua, joten hakuvaiheessa hakemuksia tulee paljon. Täten hakuvaiheessa ohjelma tavoittaa kentän hyvin. Huono puoli on, että osapuolet, joiden rahoitushakemusta ei hyväksytä, menettävät kiinnostuksensa ohjelmaa kohtaan ja ohjelmasta muodostuu vain osallistuvien tahojen keskinäinen verkostoitumistyökalu. Ohjelma sisälsi yhden hakemuskierroksen. Useampi hakemuskierros ohjelman aikana olisi voinut auttaa keskittymään ohjelmaan ja sen tavoitteiden saavuttamiseen vielä tehokkaammin koko sen keston ajan. Samalla olisi luultavasti säilytetty laajempi tieteellisen yhteisön kiinnostustaso.

Kuten edellä on mainittu, olivat ohjelmapalvelut melko vähäiset. Tämä oli kuitenkin tietoinen ratkaisu. Panostamisen kansainvälistymiseen ja verkostoitumiseen ei nähty tuovan tuntuvaa lisäarvoa ohjelmaan osallistuville tahoille, joilla on jo olemassa oleva vahva tieteellinen verkosto. Joitakin uusia kontakteja kuitenkin syntyi konsortioiden ja seminaarikeskusteluihin osallistuvien sidosryhmien välillä. Toisaalta ohjelman aikana järjestetty, nuorille tutkijoille suunnattu seminaari keräsi kehuja hyvänä esimerkkinä luoda aloitteleville tutkijoille alan verkostoja.

Konsortiotoiminta koettiin tärkeänä ja lisäarvoa tuottavana asiana. Yhtenäinen rahoitus olemassa oleville konsortioille toimi tärkeänä ajurina. Sen sijaan että aikaa ja vaivaa olisi kulunut useiden rahoitushakemuksien laatimiseen ja lähettämiseen eri rahoituslaitoksille, pystyivät tutkimusryhmät keskittymään oleellisimpaan, eli projektityöhön.

Rahoitusmallia on sikäli syytä kritisoida, että kun rahoitussumma jaetaan ryhmien kesken neljälle vuodelle, on apuraha yhtä tutkimusryhmää kohden melko pieni; joissakin tapauksessa jopa liian pieni kattamaan kokoaikaisen jatko-opiskelijan palkkakustannukset. Rahoituksen tieteellinen vaikuttavuus jää tällöin mahdollisesti melko vaatimattomaksi.

Jos rahoitusta käytetään jatko-opiskelijoiden palkkaamiseen, kuten yleensä, syntyy tieteellisiä julkaisuja ja lopulta myös tohtoritutkintoja. Nuorten tutkijoiden rahoittaminen ei kuitenkaan välttämättä johda kuin satunnaisiin kansainvälisiin läpimurtoihin.

Kaiken kaikkiaan mainittujen malliesimerkkien ja muun läpikäydyn materiaalin valossa Suomen Akatemian FinNano-ohjelma on ollut onnistunut ohjelma. Ohjelma oli hyvin koordinoitu ja se sai toteutuksensa aikana julkisuutta sekä keräsi nanosektorin tutkimusryhmät saman ohjelman alle. Saavutetut tulokset sekä ohjelmaan osallistuvien tahojen tyytyväisyys olivat hyvällä tasolla.

### Opetusministeriön Nanotieteiden hankerahoitus

Opetusministeriön Nanotieteen hankerahoituksen päämäärä oli hyvä ja valmisteluprosessi perusteellinen. Myös itse rahoitus koettiin onnistuneeksi. Onnistuminen on selitettävissä kuitenkin sillä, että Suomessa on ollut jatkuva pula tutkimusvälineiden rahoituksesta. Useimmat rahoitusorganisaatiot kieltävät käyttämästä rahoitustaan välineisiin ja usein rahoittajat uskovat, että laiterahoitus saadaan muualta.

Itse rahoitusmekanismi koettiin ongelmalliseksi, sillä yliopistojen perusrahoitusta ei ole suunniteltu ohjaamaan tutkimuksen sisältöjä. Näin ollen menettelytavat rahoituksen hakemiseen, jakamiseen, käyttämiseen sekä käytön ja vaikutusten raportointiin eivät tukeneet toisiaan. Yliopistot käyttivät rahaa autonomiansa puitteissa eri tavoin, ja rahoituksen kohdentaminen sekä vaikutusten arviointi muodostuivat hankaliksi.

Yliopistojen ohjausprosessi on muuttunut jatkuvasti kokonaisvaltaisemmaksi; yliopistot laativat strategiansa itsenäisesti ja ministeriö vastaa strategioiden yhteensovittamisesta korkeakoulusektorin kansallisten tavoitteiden kanssa. Osana tätä prosessia myös nanotieteiden hankerahoituksen tyypiset hankerahoitusmenettelyt on asteittain ajettu alas.

### Rahoitusyhteistyö

Kuten aiemmin mainittiin, FinNano-ohjelmien ja opetusministeriön hankerahoituksen välillä oli sekä virallista että epävirallista rahoitusyhteistyötä. Esimerkiksi Tekesin FinNano-ohjelmaan lähetetyt projektihakemukset lähetettiin eteenpäin Suomen Akatemian FinNano-ohjelman vastuuhenkilöille. Lisäksi näiden ohjelmien puitteissa järjestettiin yhteisiä seminaareja. Toisaalta myös Tekesin ja Akatemian ohjelmien vastuuhenkilöt osallistuivat OPM:n hankerahoituksen päätöksentekoon.

Akatemia, Tekes ja ministeriöt ovat aiemminkin tehneet yhteistyötä rahoitusinstrumenttien käytön tehostamiseksi. Yhteistyö on ollut pääosin satunnaista ja on perustunut henkilökohtaisiin yhteydenottoihin. Virallinen tai järjestetty yhteistyö, etenkin operatiivisella tasolla, on ollut harvinaista. Yhteistyö FinNano-ohjelmien ja OPM:n hankerahoituksen välillä koettiin erittäin tärkeäksi. Järjestely esti useita päällekkäisyyksiä rahoituspäätösten teossa ja lisäsi osallistujien mahdollisuuksia toteuttaa nanoprojekteja. Tulevaisuudessa vastaavanlaiset yhteistyöjärjestelyt ovat erittäin suositeltavia.

Yhteydet Nanoteknologian tutkimusohjelman ja myöhempien ohjelmien osallistujien välillä ovat olleet yllättävän vaatimattomia. Näissä ohjelmissa vaikuttaneet henkilöt olivat kuitenkin osin samoja. Tästä voidaan tehdä tulkinta, että nanosektori on vakiintunut mutta teknologiat ja tutkimusongelmat ovat kehittyneet viimeisinä vuosina niin paljon, että aihealueet, jotka olivat relevantteja 10–15 vuotta ennen nykyisiä ohjelmia, ovat jo vanhentuneita.

### Ohjelmien vaikutukset

Kuten edellä on todettu, on Nanoteknologian tutkimusohjelmalla ollut merkittävä vaikutus suomalaisen nanotutkimuksen kilpailukykyyn. Nyt – yli 10 vuotta tutkimusohjelman päättymisestä – voidaankin sanoa että vaikutukset ovat olleet melko pysyviä sekä tutkimus- että liiketoimintasektoreilla. Parhaiten vaikutukset ovat nähtävissä suomalaisen nano-osaamisen ja sektorin kilpailukyvyn kehittymisenä. Vaikka ohjelmalla on ilmeisesti ollut vain pieni vaikutus koulutukseen ja opetukseen, se on vahvistanut monia tutkimuskeskuksia. Ohjelma synnytti myös verkoston suomalaisten nanotutkijoiden välille.

Koska Nanoteknologian tutkimusohjelmien paino oli pääosin nanoteknologisessa oppimisessa, ei suoranaisia suuria innovaatioita tai kaupallisia läpimurtoja syntynyt (näitä nähtiin vasta tietyn kypsymisajan päätteeksi). Ohjelmalla ei ollut merkittäviä yhteiskunnallisia vaikutuksia, mutta toisaalta ohjelma kuitenkin keräsi siihen osallistuvat organisaatiot saman sateenvarjon alle.

Viimeaikaisilla nano-ohjelmilla on tunnistettavissa lyhyen aikavälin vaikutuksia. Ensinnäkin ohjelmat ovat olleet käytännössä ainoita nanotieteen ja -teknologian koordinoituja kansallisia rahoituslähteitä. Rahoituksen kannalta niiden vaikutus on siis ollut sektorilla valtava. Rahoitus on kiihdyttänyt tuotekehitystä ja tarjonnut tutkijoille mahdollisuuden lisätä kyseisen aihealueen tietämystään. Joissain tapauksissa ohjelmien rahoitusjärjestelyt ovat toimineet ponnahduslautana lisärahoituksen saamiseen, joka taas on vahvistanut tutkimusryhmien toimintaa entisestään.

Ohjelmat ovat myös yhdistäneet tutkimuksen ja liiketoiminnan tiiviimmäksi kuin mitä se oli ennen ohjelmien aloitusta. Voidaan jopa sanoa, että nano-ohjelmat ovat pitäneet suomalaisen nanosektorin hengissä. Tämä taas herättää kysymyksen siitä, mitä tapahtuu kun ohjelmat päättyvät. Nano-ohjelmat ovat mahdollistaneet poikkitieteellisten näkemyksien kehittymisen sekä sellaisten tutkimusryhmien muodostumisen, joita ei olisi ollut mahdollista muodostaa muilla rahoitusjärjestelyillä. Jää nähtäväksi mihin suuntaan ala näiden projektien jälkeen kehittyy. Arvioijien näkökulmasta poikkitieteelliset ja ennakkoluulottomat uudet projektit ovat yksi avain Suomen menestymiselle. Nano-ohjelmat ovat onnistuneet tukemaan tätä ajattelutapaa ansiokkaasti.

Ohjelmat ovat lisänneet nanotieteiden ja -teknologian tunnettuutta. Etenkin Tekesin rahoituksen avulla on saavutettu paljon, kun tutkimustuloksia on voitu esitellä ja tarjota teollisuuden käyttöön. Suomen Akatemian rahoitus on toisaalta tukenut tutkijoita paljon ja auttanut näitä saamaan lisärahoitusta toisista rahoituslähteistä.

Ohjelmat ovat myös tietyllä tasolla lisänneet julkista tietoisuutta nanotieteestä ja -teknologiasta. Lisäys ei ole tosin ollut kovinkaan uraauurtava. Tällä hetkellä vaikutta tosin siltä, että kun "nanoinnostus" on hiljentymässä, niin samalla julkinen keskustelu nanoturvallisuudesta ja riskeistä on vakaammalla ja objektiivisemmalla pohjalla.

## Yhteenveto

Analyysin valossa kaikki nano-ohjelmat ovat onnistuneet tavoitteissaan hyvin. Nanoteknologian tutkimusohjelman avulla saatiin kiinni nanosektorin kärkimaiden etumatkaa, lisättiin suomalaista nanotietämystä ja kerättiin eri tieteenalojen harjoittajia yhteisen teknologiakäsitteen alle. Tekesin ja Suomen Akatemian FinNano-ohjelmat piristivät suomalaista nanotutkimusta sekä -liiketoimintaa. Opetusministeriön Nanotieteen hankerahoitus taas tarjosi osan tutkimusinfrastruktuurin tarvitsemasta rahoituksesta. Yhteistyö ohjelmien välillä tapahtui lähinnä kulissien takana mutta sen avulla estettiin tutkimuksen ja rahoituksen tahattomat päällekkäisyydet sekä lisättiin rahoituksen yhtenäisyyttä.

Analyysin aikana tunnistettiin muutamia kehityskohteita, joihin ohjelmilla ei pystytä vaikuttamaan. Lisäksi voidaan todeta, että nano, yleisenä käsitteenä, on menettämässä merkitystään. Näin ollen seuraavat kehitysaskeleet tulee ottaa muulla tavoin, kuten teknologiasiirroilla, yrittäjyyskannustimilla, starttirahoituksella sekä ongelmakeskeisen perustutkimuksen rahoituksella.

Arvioinnin aikana tuli selväksi, että Suomi ei pysty yksin saavuttamaan kaikkea. Resurssit ovat rajalliset ja rohkeita strategisia valintoja on tehtävä. Tasaisesti jaettu tutkimusrahoitus johtaa väistämättä pieneneviin rahoitusosuuksiin, joka taas johtaa heikompiin tutkimustuloksiin. Tutkimusvälineistön kehittämiseen suunnattua koordinoitua rahoitusta ei Suomessa ole ja tämä johtaa tehottomiin välinehankintoihin sekä välineiden käyttöön. Lisäksi nykyiset laiterahoitusmallit eivät kannusta yhteistyöhön. Yritykset ja verkostot kärsivät epävarmuuteen liittyvistä myöhästyneistä tai kokonaan puuttuvista valinnoista ja päätöksistä. Selkeät strategiset päätökset, jotka ovat yhtenäisiä, johdonmukaisia ja ennustettavia, ovat tämän alan tulevaisuuden kannalta elintärkeitä.

## Suositukset

### Yleisesti

Suomalainen nanosektorille kohdistettu koordinoitu rahoitus päättyy, kun molemmat FinNano-ohjelmat saadaan tämän vuoden aikana päätökseen ja opetusministeriön hankerahoitus päättyi viime vuonna. Tämän arvioinnin valossa Tekesin ja Suomen Akatemian päätös olla jatkamatta nanoalan ohjelmarahoitusta on ymmärrettävää ja oikea ratkaisu:

- *Nano* yleisenä käsitteenä on liian löyhä kohdennettua rahoitusta ajatellen.
- Kansainvälisen rahoituksen painopiste on siirtymässä paradigma-ajattelusta haasteorientotuituneeksi
- Nanotieteiden sateenvarjon alle hakeutuvilla aloilla on yhä vähemmän yhteisiä nimittäjiä.

Painopiste *nanon* säilyttämiseksi omana teemanaan tulee siirtymään rahoittajilta muihin organisaatioihin. Seuraavissa luvuissa esitellään ehdotuksia ja ideoita, joita nousi esille hankkeen tiedonhankinnassa.

### Tekes, Suomen Akatemia & opetusministeriö

Nanoteknologia ja nanotiede vaikuttavat olevan tilanteessa, jossa täydentävät ohjelmalliset toiminnot eivät tuota sektorille lisäarvoa. Nano-OSKE tarjoaa verkostoitumismahdollisuuksia pk-yrityksille SHOK:it suuryrityksille. Suomen Akatemialta rahoitusta hakevilla tahoilla on jo olemassa oleva toimiva yhteistyöverkosto. Myös nanoteknologia sinänsä on päätynyt tilaan, jossa jatkobrändäys olisi todennäköisesti turhaa.

Erilaiset alkusysäykset, kuten tehokkaat rahoitusmahdollisuudet, ovat yksittäisille starttiyrityksille erittäin tärkeitä. Yksi tapa vastata yritysten aloitusvaikeuksiin on vahvistaa Tekesin NIY (nuori innovatiivinen yritys) -rahoitusmekanismia kasvattamalla rahoitusajan pituutta sekä volyymiä.

Tässä vaiheessa olemassa olevia, ohjelmista saatuja tutkimustuloksia tulee hyödyntää niin tehokkaasti kuin mahdollista. Olisi tärkeää suojata ohjelmista saatujen lupaavien tulosten immateriaalioikeudet esimerkiksi Tekesin rahoituksella.

Perustutkimuksen puolella monet tutkimustulokset toimivat automaattisesti jatkorahoitushakemusten innoittajina. Vaikka nanotutkimukseen suunnattu ohjelmarahoitus lopetettaisiin, ei muita nanoalan rahoitusinstrumentteja tulisi lopettaa automaattisesti.

Arvioinnin aikana nousi esille, että nanotutkimus on jakautunut Suomessa melko pieniin ryhmiin. Nykyinen Akatemian rahoitusjärjestelmä, jossa rahoitus jaetaan pieninä vuosittaisina summina, vahvistaa kehitystä. Olisi luultavasti hyödyllistä muuttaa rahoitusjärjestelmää siten, että se kannustaisi muodostamaan suurempia tutkimusryhmiä.

Kansainväliset rahoituslähteet suomalaiselle tutkimukselle muodostuvat koko ajan tärkeämmiksi. Kansallisten rahoituslaitosten tulisikin toimia aktiivisemmin apuna suomalaisille tutkijoille, jotta nämä voivat kohdentaa rahoitushakemuksensa tehokkaammin.

Kuten aiemmin on mainittu, opetusministeriön nanotieteen hankerahoituksella oli hyvät tavoitteet mutta rahoitusmalli on ollut haastava sikäli, että yliopistojen valtion talousarviosta tuleva rahoitus rahoitusinstrumenttina ei ole välttämättä ollut paras mahdollinen. OPM:n ohjauksen siirtyessä vähitellen yliopistojen strategioita koordinoivalle tasolle tarkastellun kaltaiset hankerahoitusjärjestelmät onkin lopetettu.

On kuitenkin huomattava, että mikäli kokeellinen nanotiede halutaan osaksi suomalaista tutkimusportfoliota, välinerahoitusta tulisi uudistaa. Riippumatta rahoitusmekanismista välinerahoitus ei saisi perustua niinkään välineiden omistusoikeuteen, vaan välineiden käytön mahdollistamiseen ja tähän liittyviin palveluihin:

1. Rahoitusmekanismien tulee olla tehokkaammin koordinoituja ja niiden tulee mahdollistaa katkeamaton rahoitusvirta. Koska tutkimusvälineet ovat kalliita, täytyy rahoitettavien osa-alueiden suhteen tehdä strategisia päätöksiä. Ainoastaan nanotieteisiin keskittyvän, pienen mittakaavankansallisen roadmap-hankkeen toteuttaminen olisi todennäköisesti hyödyllistä.
2. Rahoitusmekanismien kehittämisen myötä myös seurantamekanismeja täytyy parantaa.
3. Rahoituksen tulee edistää yhteistyötä.
4. Rahoituksen tulee perustua suunnitelmaan, josta ilmenee välineistön vaikuttavuus.
5. On kyettävä takaamaan, että välineistöä käytetään sen koko elinkaaren ajan.
6. Välineistön huolehtimista varten on oltava tarpeeksi henkilökuntaa.

Ammattikorkeakoulujen (AMK) roolin määritteleminen Suomen innovaatiojärjestelmässä on ollut melko haastavaa johtuen mm. niiden erilaisista organisaatiomuodoista. Tässä raportissa arvioiduissa ohjelmissa oli vain muutama AMK mukana. Aiemmissa arvioinneissa on todettu että yksi rooli AMK:lle olisi toimia soveltavien tutkimusprojektien systeemi-integraattoreina ja asiantuntijoina projekteissa, jotka vaativat monitieteellistä mutta käytännöllistä lähestymistapaa. Nanoteknologia on kuitenkin alue, jossa tarpeita tällaiselle asiantuntemukselle ei toistaiseksi ole. Tilanne saattaa muuttua tulevaisuudessa, mutta tänä päivänä AMK:n rooli nanoteknologiatutkimuksessa tulee määrittää tapauskohtaisesti.

Rahoitusorganisaatioiden välinen yhteistyö on ollut merkittävässä roolissa, mutta se on perustunut omaksuttuihin toimintatapoihin ja aktiivisten henkilöiden toimintaan. Olisi erittäin tärkeää formalisoida sekä yhteistyötarpeiden arviointi että yhteistyön toteuttaminen siten, että yhteistyö erityisesti erilaisten hankkeiden valmisteluvaiheessa tulee varmasti tehdyksi. Organisaatiot ovat alkaneet tehdä entistä enemmän strategisen suunnittelun yhteistyötä yli hallinnonalojen, mikä edistää toimien yhteensopivuutta ja helpottaa rahoituksen käyttäjien työtä.

### Yhteistyöorganisaatiot

Yhteistyöorganisaatioiden rooli korostuu, mikäli rahoitusorganisaatiot vähentävät nano-käsitteen esillä pitämistä. Aiemmin tuli esille, että Nano-OSKE on listannut yli 400 nanosektorin yritystä ja toimii vahvana alueellisena verkosto-organisaationa. Toisaalta yritykset, jotka osallistuivat nano-ohjelmiin, tunsivat OSKE:n toimintaa melko heikosti. OSKE-toiminnasta olisi syytä tiedottaa enemmän yrityksille. Lisäksi alueellisten Nano-OSKEjen tulisi koordinoida työtään tehokkaammin, esimerkiksi erikoistumalla OSKE-toiminnan eri osa-alueisiin. Tällä tavoin Nano-OSKE osallistuisi tehokkaasti nano-brändin ylläpitämiseen ja nanosektorilla toimivat yritykset eivät olisi yksin tämän tavoitteen kanssa.

Tämän arvioinnin valossa nanosektorin ja Strategisen huippuosaamisen keskittymien välinen kytkentä on käytännössä olematon. Tämä on ymmärrettävää, sillä SHOK:t ovat vasta muodostumassa. SHOK:ien tulisi kuitenkin ottaa keskeisempi rooli nanoteknologian edistäjinä, sillä yksi suurimmista ongelmista Suomen nanoteknologian ja -tutkimuksen alueella on, että yritykset eivät hyödynnä nanoteknologian koko potentiaalia. Yksi mahdollisuus toteuttaa tämä olisi pyrkiä käynnistämään 2–3 SHOK:n, Tekesin ja Suomen Akatemian yhteisrahoitteinen EIT KIC (E*uropean Institute of Innovation and Technology, Knowledge and Innovation Community*), jolla edistettäisiin nanoteknologian tutkimusta ja kehitystä SHOKien sisällä.

### Uudet avaukset

Suomessa toimii useita kansainvälisesti tunnettuja nanoterveyden sekä vedenkäsittelyn ja ympäristön nanopartikkeleiden monitoroinnin tutkimusryhmää ja yritystä. Eräänä ennakkoluulottamana mahdollisuutena olisi lisätä alojen ja nano-brändin näkyvyyttä perustamalla keskustyyppisiä tutkimus- ja yhteistyöyksiköitä alalle.

Muutama vuosi sitten Nokia, yhdessä Tekesin ja Technopolisin kanssa, perusti Nokia – Technopolis Innovation Mill -ohjelman. Ohjelman tarkoituksena on siirtää innovaatiot, joita Nokia ei pysty itse hyödyntämään, kasvaville kotimaisille yrityksille jatkojalostusta ja hyödyntämistä varten. Samanlaista lähestymistapaa voitaisiin hyödyntää myös nanosektorilla; Nano-OSKE voisi perustaa Nano Innovaation Mill -konseptin, jossa Tekes toimisi rahoittajana. Innovaatioiden keräämisen ja jakamisen lisäksi nuoria ja kasvavia yrityksiä voitaisiin myös opastaa innovaatiotoiminnassa.

Nanotech Finlandilla – Tekesin, Suomen Akatemian ja OSKE:n muodostamalla nanoteknologian pääverkostolla on merkittävä brändäävä rooli. Nanotech Finland -verkosto tekee suomalaisesta nanoteknologiasektorista yhtenäisen kokonaisuuden. Verkosto on soveltuva osapuoli säilyttämään Suomen nanotieteen kansainvälisen näkyvyyden. Näkyvyyttä voidaan parantaa esimerkiksi pyrkimällä muodostamaan innovaatioklustereita Kiinan ja Venäjän kanssa. Tähän vaadittava rahoitus voisi tulla ainakin osittain Tekesiltä.

# 1 Introduction

Nanotechnology is a global mega trend, in which governments and companies are estimated to have invested over EUR 20 billion. Nanotechnology offers an opportunity to develop an entirely new kind of technology based on the functional properties achieved at the nanoscale.

Nanotechnology will have a significant effect on society and people's everyday lives. It is believed that in the future nanotechnology can be used for manufacturing smaller and more powerful electronic devices, materials with completely new qualities, new ways of producing energy and better medical diagnostics and targeted drugs. Finland has recognised the significance of nanotechnology. The development in the field is driven by cooperation between science and industry. The Finnish innovation system effectively promotes the exploitation of research results in industries and the creation of new businesses.

This study reports the evaluation of Tekes' FinNano programme 2005–2010, the Academy of Finland's nanoscience research programme FinNano (2006–2010), the Ministry of Education's nanoscience funding 2007–2009, and Tekes' and the Academy of Finland's nanotechnology programme 1997–1999. The evaluation focuses on the objectives, results and impacts of the programmes as well as examines the context of the programmes. Cooperation between the programmes is also analysed.

The evaluation was arranged and funded by Tekes – the Finnish Funding Agency for Technology and Innovation, the Academy of Finland and the Finnish Ministry of Education and Culture. The evaluation was conducted under the supervision of a steering group. The members of the steering group were Pekka Pesonen (Tekes), Markku Lämsä (Tekes), Erja Heikkinen (Ministry of Education and Culture) and Anssi Mälkki (Academy of Finland).

The evaluation was carried out by a consortium led by Gaia Consulting Ltd. The members of the evaluation team were Tuomas Raivio, Alina Pathan, Piia Pessala, Tiina Pursula and Jatta Aho (Gaia Consulting Ltd), Kaarle Hämeri (University of Helsinki/Finnish Institute of Occupational Health) and Jukka Teräs (Norrum Ltd).

## 1.1 Terminology

Many Finnish universities and ministries have changed their name during the evaluation timeframe. In this report we use the names that the bodies had at the time of the activities. In Table 1, we outline the central changes, and abbreviations used in the evaluation.

**Table 1. Principal changes in organisations, and abbreviations used in the evaluation.**

| Former name | Abbreviation | Present name | Abbreviation |
|---|---|---|---|
| Science and Technology Policy Council of Finland | STC | Research and Innovation Council. | RIC |
| Ministry of Education | MoE | Ministry of Education and Culture | MoEC |
| Ministry of Trade and Industry | MoTI | Ministry of Employment and Economy | MoEE |
| Helsinki University of Technology | HUT | Aalto University, School of Science and Technology | AU |
| University of Kuopio | UKU | University of Eastern Finland | UEF |
| University of Joensuu | JoU | University of Eastern Finland | UEF |
| Tampere University of Technology | TUT | - | |
| Academy of Finland | Academy | - | |
| Finnish Funding Agency for Technology and Innovation | Tekes | - | |

# 2

# Evaluation framework

## 2.1 Evaluation questions

The evaluation questions as per call for tenders were the following:

**Objectives and results for the nano programmes**

1. How relevant and challenging were the objectives? How have they fulfilled national strategic choices?
2. How have the objectives been realised? What other results that support the set objectives have been gained (as case examples)?
3. What results were gained that are outside the set objectives? Which results would not have been realised without the programmes?
4. How well did the programmes reach the most important client groups?
5. How well did the programmes, their services and management respond to the needs of the participants? Especially, how has the international cooperation of the programmes affected the participants and clients?

**Impacts of the programmes and operational environment**

1. What kind of impacts have been realised or are expected to be realised in the programmes? How broad, stable or important can these impacts be considered as being?
2. How and to what extent have the programmes had an effect on
   - R&D and i investment in the nano sector
   - Development of know-how, researcher training and establishment of knowledge clusters
   - Transfer of experts between different actors in the nano sector
   - Formation of national and international networks
   - Important innovations and business opportunities
   - Reputation of nanotechnology, overall discussion and changes in attitudes
   - Business and society in a broader view
3. What impact has the cooperation (timing, coordination) between the funding bodies had on the successfulness and effectiveness of the programmes?

In addition to the evaluation questions presented above, conclusions and recommendations on the following three themes were to be stated:

***A. R&D and investment activities within the nano sector:***

How could R&D and investment activities be developed? What is the role of SHOKs and OSKEs in the future? Which international programmes and initiatives are the most important for the nano sector and how could they be influenced more?

***B. Funding bodies:***

What concrete and working practices can be identified to develop programme services and activities? What recommendations there are to develop the funding cooperation and other activities of the funding bodies (Tekes, Academy of Finland, Ministry of Education and Culture)?

***C. Research and innovation policy:***

How should the recommendations from the evaluation of the national innovation strategy and innovation environment be taken into consideration? What other measures are needed in the research and innovation policy to improve the effectiveness than the activities of the funding bodies?

## 2.2 Methodology

The evaluation data collection and analysis was carried out using the methods described below:

**A. Document analysis**

The evaluation was started with a document analysis, where relevant programme documentations, especially reports relating to the preparation of the programmes, minutes of programme management meetings, project descriptions, final reports, evaluation reports, and funding applications were scrutinised. Questions regarding the documents were formed based on the evaluation questions.

**B. Background interviews**

Besides the document analysis, background interviews were carried out to form a baseline for the evaluation. The interviewees (altogether 10) had been involved in initiating, planning and/or running the nano and/or nanoscience and nanotechnology programmes. The selection of interviewees was approved by the evaluation steering group and the interviews were carried out as structured face-to-face interviews. The interview structures followed the evaluation question settings.

**C. Stakeholder interviews**

In order to obtain an overall picture of the nano sector, as well as views on the success and impacts of the nano programmes, stakeholder interviews were carried out. The interviewees were selected together with the evaluation steering group and it was ensured that a range of viewpoints, such as political, scientific and technological, were covered. Ten stakeholders representing, for example, companies, universities and research organisations were interviewed. The interviews were carried out mainly as structured face-to-face interviews where the structure again followed the evaluation question settings relevant for the interviewees.

**D. Micro cluster analysis**

In-depth analysis of the programmes as well as of funding cooperation was carried out through seven micro clusters. In the analysis, developed by the evaluators in earlier studies, thematically coherent or otherwise representative project samples from the programmes were selected, and in-depth interviews were carried out with the project managers. The interviews were structured to fit the evaluation questions. By carrying out the interviews for each project in the sample, both a coherent view on the evaluation questions was obtained and individual project results were collected.

This method allows a broader perspective on the specific programmes than would be possible through studying the results and impacts of single projects funded by the programmes. However, due to the varying nature of the programmes, the micro clusters and their composition in this evaluation vary from each other considerably.

The micro cluster division and themes were decided by the evaluation steering group as follows:

- A sample of projects from the Nanotechnology programme
- Nanohybtonite – nanocarbon tube reinforced epoxy resin innovation chain
- Two samples of projects in Tekes' FinNano programme
- A sample of projects in the Academy of Finland's FinNano programme
- Case studies of the major receivers of the Ministry of Education's funding for nanoscience
- Sample of groups participating both in Tekes' and the Academy of Finland's FinNano programmes with the equipment procured by the Ministry of Education's nanoscience funding

Altogether nearly 40 persons were contacted and interviewed in the micro cluster analysis.

**E. Workshop**

In the last phase of the evaluation a workshop was held with 11 participants who had already been involved in the evaluation process through interviews, etc. The workshop aimed at validating and refining the initial evaluation results. In addition, development perspectives for nano R&D and investment activities in Finland were generated.

## 2.3 Assessment of validity

It should be noted that the micro cluster analysis outlined above is a qualitative method with a non-random sample. This means that the direct generalisation of the results of the analysis must be supported with other methods, as is done here. Qualitative analysis has been a conscious choice which has been made to support the positive learning aspect of this evaluation. Furthermore, the evaluators' experience in quantitative methods in programme evaluation suggest that the response rate of different questionnaires, for example, usually remain too small to draw any firm conclusions, either.

The interviewees have been selected so as to represent all the views that arise in this evaluation. Interviewees naturally reflect their own opinions, but these opinions usually represent the reality in which they operate. Participatory methods such as workshops are targeted to seek consensus and to elaborate possible discrepancies and inconsistencies.

The evaluators consider that with the given resources, the methods and coverage of data gathering and analysis provide a fairly unbiased and valid view of the nanoscience and technology field in Finland.

# 3
# Evaluation targets

## 3.1 Tekes' & the Academy of Finland's nanotechnology programme 1997–1999

The nanotechnology research programme was carried out during the years 1997–1999. It was the first programme to be planned and co-financed by the Academy of Finland and Tekes, and addressed both scientific and technological issues. The financing of the programme amounted to FIM 43.9 million, of which the Academy of Finland financed FIM 18.3 million[1] and Tekes FIM 25.6 million[2]. A total of 14 projects were financed in the programme. Industrial funding was negligible, as it was not considered to be a prerequisite. Programme evaluation was carried out by Edward T. Yu and Christiane Ziegler in autumn 1999[3].

The objectives of the programme were defined at a general level to address the following identified areas:

- Intense and rapidly growing interest in nanotechnology internationally
- Enormous industrial potential foreseen for nanotechnology
- Need to educate researchers equipped to explore new ideas in nanotechnology in order to help realise this potential within Finland
- Need to increase the prominence of Finnish research in nanotechnology and related areas
- Desire to foster new, interdisciplinary interactions leading to new, unforeseen opportunities for creativity and innovation
- Need to fill the gap that exists between so-called basic research (normally funded by the Academy of Finland) and applied research (normally funded by Tekes) and to find ways to increase cooperation between these organisations

The research tasks of the programme were organised under five headings[4]:

1. Nanobiology
2. Self organised structures
3. Functional nanoparticles
4. Nanoelectronics
5. Biomaterials for information technology

## 3.2 Tekes' FinNano programme

The FinNano technology programme of Tekes (Tekes FinNano) studied, utilised and commercialised nanoscale systems and phenomena. In the programme, nanotechnology was seen as horizontal and enabling, and it is associated with at least three aspects: scale, functionality and the controllability of nanostructure. The approach was intended to be genuinely multidisciplinary. The programme was prepared by means of a thorough report that described the Finnish nanotechnology field in great detail.

The objective of the programme was to strengthen Finnish nanotechnology research in selected focus areas and to accelerate the commercial development of nanotechnology in Finland. The programme emphasised effective use of research results and promoted close collaboration between research and industry. Specific targets were to:

1. Strengthen existing Finnish research, research facilities and to build new competencies in multidisciplinary research groups and development centres
2. Enhance business development by transforming the research results into technologies and products and strengthen and secure the commercial development of nanotechnology

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1 The Academy's funding was incorporated in the ongoing Academy research programme on materials and structures (MATRA).
2 Tekes (2000)
3 Yu and Ziegler (2000)
4 Tekes (2000)

3. Support national and international networking and researcher mobility
4. Promote the participation of Finnish researchers, research facilities and companies in EU nanotechnology-related R&D programmes
5. Strengthen regional centres of excellence and link them to international settings
6. Promote efficient and synergetic resource and infrastructure usage
7. Encourage companies to see the possibilities of nanotechnology and provide good opportunities to utilise the applications of nanotechnology

Specific focal points of the programme were

**A.** Innovative nanostructures and materials
**B.** Nanosensors and actuators
**C.** New solutions of nanoelectronics

The programme's project portfolio included more than 100 research and industrial technology development projects. Research was led by high-level consortia in cooperation with both international research organisations and industry. The programme involved approximately 170 companies which had either their own development project or were funding a research project.

The total volume of the programme was approx. EUR 70 million, of which Tekes's share was EUR 47 million. The duration of the programme was five years, 2005–2009, and it was carried out in close cooperation with the Academy of Finland's Nanoscience Research Programme.

## 3.3 Academy of Finland's FinNano programme

24The Academy of Finland's Research Programme on Nanoscience (Academy FinNano) emphasised an interdisciplinary approach in nanoscience research. The programme combined nanoscale research in chemistry, physics and biosciences, and supported overall development of the field in Finland. The thematic areas covered themes where supporting basic research can generate considerable potential in terms of innovative basic research knowledge, sustainable development and industrial competitiveness.

The objectives of the programme were to

- Support high-level basic research in nanoscience as part of the innovation environment
- Activate interdisciplinary and transdisciplinary approach in the field
- Create tangible added value for research teams participating in the programme in terms of networking, international visibility and exploitation of research results
- Advance responsible development of nanotechnology – the research programme will take in to account ethical challenges, i.e. safety, health and environment related issues
- Advance European and other international activity and mobility in the field

The programme consisted of 10 Finnish consortium projects which have been funded for 2006–2010. In addition, five Finnish-European and Finnish-Russian projects were funded in cooperation with international partners. The total volume of the Finnish projects and Finnish partners is EUR 9.45 million.

The final programme consortia can be classified under the following topics:

- Nanoparticles and -structures in life sciences and medicine (PEPBI, Transpoly, Biotarget)
- Material properties of nanodevices and structures (Funano, Fernand, Nanofused, Nanofridge)
- Properties of nanostructures (MEP, Nanotomo, OPNA, and four projects jointly funded by the Academy of Finland and the Russian Foundation for Basic Research)
- Health and safety issues related to nanoparticles (Nanohealth)

The Academy's FinNano was carried out in cooperation with the Tekes' FinNano. The programmes had joint planning and other activities, such as seminars and information material.

## 3.4 Ministry of Education's nanoscience funding 2007–2009

The Finnish Ministry of Education (MoE) allocated altogether EUR 19 million to the Finnish nanoscience sector during the period 2007–2009. The MoE's nanoscience funding was not project funding, but rather funding within operating expenses from the State to the universities, which was targeted specifically to nano-related activities. The MoE's nanoscience funding originated in the programme-based funding scheme that the MoE had been running to enhance selected disciplines or processes. The MoE appointed a working group to scrutinise the Finnish nanoscience research and the education field and to provide recommendations for a nanoscience development programme. As a result, three spearhead areas within Finnish nanoscience were identified and proposed to be of special interest in the new nanoscience funding programme[5].

Based on the recommendations of the MoE's committee, the main objectives for the funding to[6]:

- Strengthen research prerequisites, especially in the identified spearhead domains (nanomaterials, nanoelectronics and -photonics, and nanobiotechnology)
- Enhance cooperation, coordination and pooling of, for example, existing knowledge clusters, infrastructure and education
- Enhance knowledge transfer and commercialisation of research findings

It was also noted that the input should promote the goals of both ongoing FinNano programmes. By and large, the funding has been viewed as being directed mainly at infrastructure enhancement as, for example, Tekes and the Academy of Finland do not fund projects of this kind.

The application and funding allocation round differed from other Finnish funding instruments of a programme type. Universities were informed about the open nanoscience programme as a part of their standard performance contract negotiations. Consequently, the applicants for funding were universities as a whole, not individual researchers or research groups. The applications were assessed jointly by the MoE, Tekes and the Academy of Finland. The funding decisions were based on the applications and were made in 2006 for the subsequent three-year period, but the agreed sums were granted each year separately.

The funded universities were Tampere University of Technology, the University of Jyväskylä, the University of Joensuu, the University of Helsinki, Helsinki University of Technology and the University of Oulu (see Table 2). The applications contained information on how the universities intended to use the funding. These included, for example, the purchase of specific equipment, salaries, education and travel. The MoE allocated funding mainly for updating and maintaining the research infrastructure environment. The universities used their autonomy and discretion to direct the funding to selected operations..

## 3.5 Cooperation between the funding bodies

All the latter programmes (excluding the Nanotechnology programme) cooperated throughout their life cycles. The baseline for this cooperation was that the programmes should be organised and executed to complement and support each other.

The first programme to start was Tekes' programme. The MoE did not participate in the preparation of the Tekes programme, but later on the MoE participated in, e.g. workshops arranged by Tekes. There was more cooperation between the MoE and the Academy – already during the startup of the funding programmes. The aim was for the Academy's programme and the MoE's funding for nanosciences to start at the same time. Ultimately, however, the Academy's programme start-

**Table 2. MoE's nanoscience funding during years 2007–2009**

| University/Funding k€ | Year | | | Total |
|---|---|---|---|---|
| | 2007 | 2008 | 2009 | |
| University of Helsinki | 1,500 | 1,500 | 1,000 | 4,000 |
| University of Jyväskylä | 1,500 | 1,500 | 1,750 | 4,750 |
| University of Oulu | 200 | 200 | 200 | 600 |
| University of Joensuu | 800 | 300 | 300 | 1,400 |
| Helsinki University of Technology | 2,540 | 1,500 | 1,500 | 5,540 |
| Tampere University of Technology | 1,000 | 1,000 | 1,000 | 3,000 |
| **Total** | **7,040** | **5,500** | **5,750** | **19,290** |

5 Moe (2005)

6 Moe (2005), English summary

ed later. Nevertheless, it is hard to ascertain how much the information provided by MoE affected the preparation of the Academy of Finland's programme.

Representatives from both Tekes and the Academy took part in the spearhead analysis carried out by the working group appointed by the MoE, and the spearheads were finally agreed in consensus. Moreover, all of the applications for the MoE's nanoscience funding were analysed in cooperation with Tekes and the Academy. The applicants were chosen so that they were compatible with the objectives set by the working group and in line with the nanofunding of Tekes and the Academy. Most importantly, the objectives were to avoid overlapping between the three funding programmes and to support the programmes of Tekes and the Academy with MoE nanoscience funding. One of the methods to enhance cooperation was to select the same people for the steering groups of each programme.

The cooperation between the Tekes and Academy programmes was more intense, whereas collaboration with the MoE programme was most active in the decision-making phase before the funding period 2007–2009. The Tekes and Academy programmes had joint events, there were multiple research groups which participated in both Tekes' and the Academy's programmes, and information about the ongoing projects was passed between the programmes. In practice, the cooperation between Tekes and the Academy was most intense during the application analysis phase. Overall, cooperation was most apparent and clearest among the programme leaders, but was not so evident across the participants.

# 4

# Nano programme context

The nano sector is more of a cross-sectoral theme than a uniform nano discipline. However, research that focuses on nanoscale objects and phenomena is often called nanoscience, whereas the technology taking advantage of these nanoscale objects is referred to as nanotechnology. These definitions are used also in this evaluation and are defined in more detail in the sections below. This section describes the current position of nanoscience and nanotechnology in Finland and depicts their overall operational environment in Finland.

## 4.1 Definitions

### Nanoscience

Nanoscience consists of a wide range of topics, methods and applications which share concepts and physical laws that prevail only at the nanometre scale. Research in nanoscience is typically interdisciplinary in nature and covers a wide range of traditional scientific fields. Nanoscience deals with objects and phenomena that appear when the characteristic dimension of the system is below about 100 nm. At this size-range, the physics that govern the macroscopic world do not fully apply, rather other phenomena become important. These phenomena include the increasing role of surface atoms, the unclear definition of surface for clusters consisting of just a few atoms, the curvature effects of small objects and the increasing importance of quantum mechanics. The common unifying concepts and physical laws that prevail in the nanoscale can be termed collectively "nanoscience".

Nanoscience has been defined somewhat differently depending on the purpose and context. The National Science Foundation's US National Nanotechnology Initiative (US NNI) gives the following definition[7]:

1. Research and technology development at the atomic, molecular and macromolecular levels, in the scale of approximately 1–100 nanometre range
2. Creating and using structures, devices and systems that have novel properties and functions because of their small and/or intermediate size
3. Ability to control and manipulate on the atomic scale

The EU defines the field as follows: Nanosciences and nanotechnologies are new approaches to research and development that concern the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a large scale[8].

Both of these definitions consist of identification of a size-scale as well as appearance of fundamentally different phenomena taking place within this size-range. In simple terms, we may define **nanoscience as the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale**. Therefore a wide range of topics appear under the umbrella concept of nanoscience. The diversity is further exaggerated by the hype covering the topic of nanoscience. As there is more funding focused on the topic of nanoscience and –technology, sometimes also conventional science tends to appear under the nano-topic.

### Nanotechnology

In contrast to nanoscience, the term "nanotechnology" refers to the development of a mature know-how for the production of nano-objects and the exploitation of knowledge progress on specific nano-objects to make concrete applications. Nanotechnology is closely re-

7 www.nano.gov (11.5.2010)
8 COM243

lated to nanoscience but obeys distinct drivers in so far as nanotechnology tries to respond to particular needs, while nanoscience is primarily turned towards the discovery and study of novel phenomena and the creation of new concepts to describe them. Nanotechnology is the way discoveries made at the nanoscale are put to work[9].

The definition of nanotechnology has proven to be a difficult task. The most common nanotechnology definitions currently available include, e.g. the US NNI, the EU's 7th Framework Programme, Japan's Science and Technology Plan, and ISO definitions. As an example, the US National Nanotechnology Initiative states[10]: "Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale". The threshold of 100 nanometres has been frequently used in defining nanotechnology. The threshold of 100 nanometres is, however, only indicative of a point along the continuum where classical rules of physics start to give way to new nanotechnology phenomena.

The development of nanotechnology is approached from two main principles, top down and bottom up. According to the evolutionary top-down principle, microtechnology is gradually scaled down into nanotechnology (under 100 nm). This top-down principle approach manipulates materials down to the nanoscale through elaborations of various techniques such as, e.g. lithography, cutting, or milling techniques. According to the revolutionary bottom-up principle, entirely new structures (including materials) and manufacturing processes are created by applying top science (so-called self-assembly, as in biology). The bottom-up approach creates new materials at the nanoscale through, e.g. nanoparticle synthesis, and liquid-phase processes. The top-down approach has already created plenty of new technology companies and new industrially applicable products and production processes. In the long term bottom-up technology is expected to revolutionise production methods in many areas.

## 4.2 Global nanotechnology and nanoscience research and development

Nanotechnology – and the promises of the impacts of nanotechnology-enabled products – attracts a broad range of interest groups globally, including the R&D community, the industrial world, and political decision-makers. Public R&D investments have rapidly increased in the field of nanotechnology. Nanotechnology applications penetrate into various fields of industrial activity such as, e.g. cars, electronics, health, clothing, and sports.

As nanoscience and nanotechnologies cover such a wide range of fields (from chemistry, physics and biology, to medicine, engineering and electronics), it is not straightforward to characterise the research in simple terms. One possible way to describe nanoscience is to consider it in four broad categories:

1. Nanomaterials
2. Nanometrology (measurement at nanoscale)
3. Electronics, optoelectronics and information and communication technology
4. Bio-nanotechnology and nanomedicine

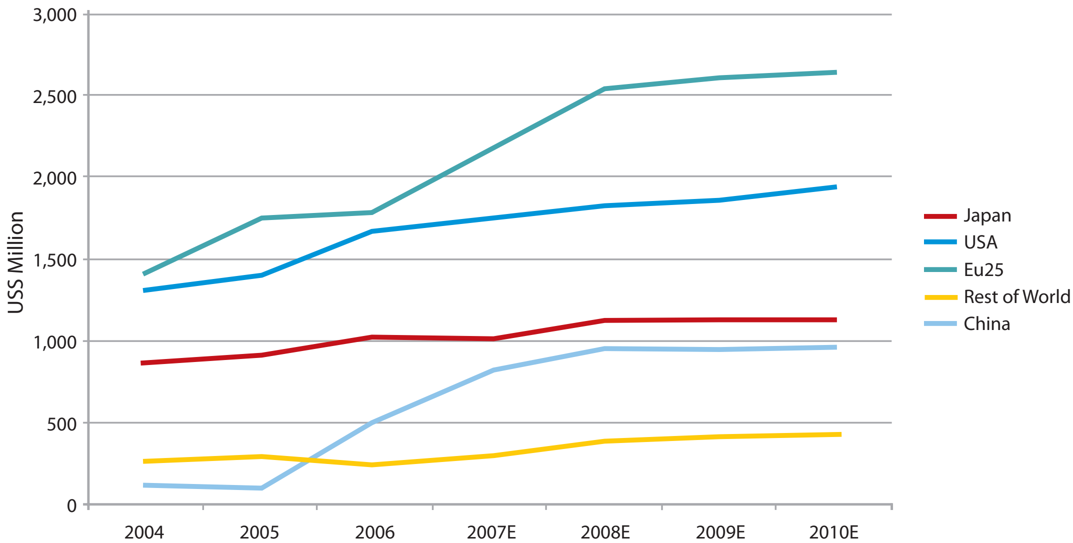
This division helps distinguish between developments in different fields, but there is naturally some overlap.

Research in nanoscience has attracted increasing funding during approximately the last 10–20 years. Current investments worldwide are in the order of USD 10 billion annually. In the EU's 6th Framework Programme 2003–2006, nanotechnology research was funded by EUR 1.37 billion, and during the first 2 years of the EU's 7th Framework Programme funding already totalled EUR 1.1 billion In 2007–2008, global expenditure on nanotechnology research reached EUR 24 billion, of which Europe accounted for one quarter.[11]

Nanotechnology-related R&D activities are concentrated in a only few countries and regions of the world. The United States, Japan and some of the larger European Union countries (Germany, France, and the United Kingdom) have been the largest public investors in R&D nanotechnology[12] (Figure 1). New countries such as China, India, and Ko-

9 NNI (2007)
10 NNI (2000)
11 e.g., Nanosciences and Nanotechnologies: An action plan for Europe 2005–2009. Second Implementation Report 2007–2009. European Commission.
12 Roco (2007)

**Figure 1. Government Nanotechnology Funding in Major Economies (2008–2010 estimated).**




rea are rapidly entering the nanotechnology R&D field and are likely to change the overall picture of R&D investments in the coming years.

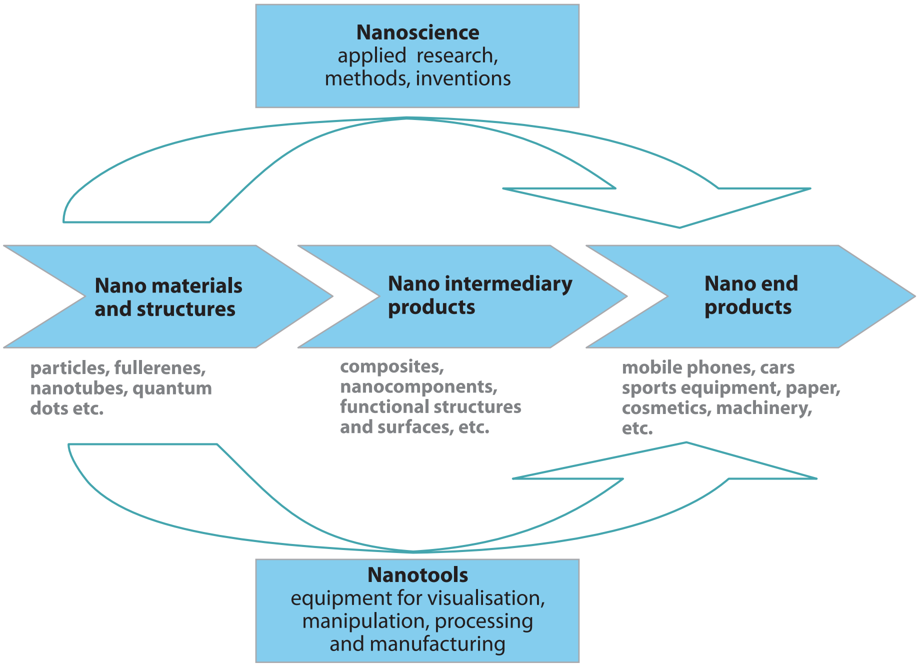
The OECD has compared nanotechnology market forecasts since the early 2000s[13]. The global market forecasts for nanotechnology products range from USD 750 billion to USD 3100 billion by the year 2015, and some 2 million new jobs could be created. All the market forecasts analysed by the OECD predict a very rapid growth of the market for nanotechnology products in the coming years. For example, Lux Research estimates that the figure of USD 147 billion worth of nano-enabled products produced worldwide is set to grow to USD 3,100 billion in 2015[14]. The global market forecasts currently available do not take into account the effect of the current global economic crisis on the market estimates. Some analysts note, however, that the sudden collapse in consumer spending will erode the business model of many established companies and give them a stimulus to embrace new, nanotechnology enabled technologies[15].

There are simultaneous processes going on among and between actors in nanotechnology. The road from research to end product is often expected to be long and expensive, and the resources of private sector actors, especially SMEs, are often insufficient to bring the product to global markets profitably. New forms of cooperation between research, large companies, and SMEs will play a central role in growing the nanotechnology business opportunities and markets. Figure 2 presents the value chain of business based on nanotechnology and various associated areas of expertise.

The literature on nanotechnology includes a large number of nanotechnology applications, ranging from new materials for semiconductors in electronics and communication to miniaturised diagnostics that could be implanted for the early diagnosis and monitoring of illnesses, techniques to clean up hazardous chemicals in the environment, and scratch- and glare-resistant coatings applied to eye glasses, windows, and car mirrors. Relatively little is yet known about the distribution of nanotechnology products between countries and technology sec-

13 OECD (2009)
14 Lux (2008)
15 Cientifica (2009)

**Figure 2. The value chain of business based nanotechnology and various areas of expertise connected.**[16]




tors. Several attempts have made been to produce an international inventory of nanotechnology products. As an example, the Woodrow Wilson nanotechnology product inventory currently includes 1,015 nanotechnology products from 24 countries[17].

The emerging nature of nanotechnology and the variety of nanotechnology definitions make the estimation of the commercial potential of nanotechnology applications a highly challenging task. The critical issue is the definition of nanotechnology products (the nanocontent, see, e.g. Berger 2007)[18]. Moreover, in analysing the data on nanotechnology companies and their products, it is important to find out if the companies listed in the statistics are "true" nanotechnology companies that base their operations on nanotechnology, or if they utilise to a certain extent nanotechnology to serve their customers. For example, the Swedish statistics on nanotechnology includes 117 companies, of which only 45% are classified as "true" nanotechnology companies in Sweden[19].

## 4.3 Nanoscience in Finland

Finnish nanoscience state of the art has been reviewed several times. The baseline for the millennium was drawn up by CSC – IT Center for Science Ltd[20]. The review of Finnish research in nanoscience during 2005 and its summary report[21] published by the MoE served as background information when calls for FinNano research programmes by the Academy of Finland and Tekes were made. The latest summary is given in the Tekes FinNano report[22].

16 OSKE Nanotechnology (2007)
17 Wilson (2010)
18 Berger, M. (2007)
19 Vinnova (2007)
20 Koponen et al. (2002)
21 MoE (2005)
22 Nanotech Finland (2007)

According to the most recent report, universities and public research institutes hosting groups and centres focusing on nanotechnology are

- University of Helsinki
- Helsinki University of Technology
- VTT – Technical Research Centre of Finland
- Finnish Institute of Occupational Health
- CSC – IT Center for Science Ltd
- Centre for Metrology and Accreditation, Mikes
- University of Turku
- Åbo Akademi University
- University of Tampere
- Tampere University of Technology
- University of Jyväskylä
- University of Kuopio
- University of Oulu
- Lappeenranta University of Technology

Based on this evaluation, the University of Joensuu has been added to this list.

The most productive research laboratories within nanoscience in Finland were identified by the MoE working group in 2005. The working group reported internationally recognised research[23] at Helsinki University of Technology (Department of Technical Physics and Low Temperature Physics), the University of Helsinki (Departments of Physics and Inorganic Chemistry), VTT (biotechnology and information technology) and the Jyväskylä Nano-Science Center. It seems that during the past five years, many other groups in other universities and institutes have proceeded with internationally recognised results in nanoscience, too, but there are no recent scientific evaluations available.

Central strong themes in the Finnish nanosciences are depicted in Table 3 with examples of universities and departments hosting groups and institutes that focus on the topic.

Finnish research in the field of nanoscience has been systematically developed under national research programmes funded by the Academy of Finland and Tekes. A good snapshot of the current state of the art in Finnish research can be obtained by viewing the research outlined in the FinNano programmes.

The research fields under **the Academy's FinNano programme** were preliminarily classified in three main thematic areas: directed self-assembly, functionality in nanoscience and properties of single nanoscale objects. These topics served as the starting point of the programme, but the final form was developed based on the evaluation of the research proposals.

**Table 3. Strong themes in the Finnish nanosciences with examples of universities and departments hosting groups and institutes that focus on the theme.**

| Field | Examples of universities, departments & institutes |
|---|---|
| Theoretical studies and simulations | Helsinki University of Technology, Jyväskylä University , University of Helsinki (especially formation processes of nanostructures), University of Oulu; CSC – IT Center for Science Ltd |
| Nanoelectronics and thin films | Helsinki University of Technology, especially Low Temperature Laboratory, VTT Computer Science, VTT Oulu, Jyväskylä University, University of Helsinki Department of Organic Chemistry |
| Nanophotonics | Tampere University of Technology Optoelectronics Research Center (ORC) & Departments of Chemistry and Physics, University of Joensuu, Micronova |
| Carbon nanotubes and fullerenes | Åbo Akademi, Jyväskylä University, Helsinki University of Technology |
| Nano chemistry (also research of molecular structures and molecular engines) | Jyväskylä University, Helsinki University of Technology, Tampere University of Technology, University of Helsinki, Åbo Akademi |
| Nano biosciences (research topics linking biological research with the nanometer-scale applications and approaches and ranging from virus research to biomaterials and computational biosciences) | VTT, University of Helsinki, Helsinki University of Technology, Tampere University of Technology, Jyväskylä University, University of Turku, University of Kuopio |
| Occupational and environmental health and safety | Finnish Institute of Occupational Health (FIOH), National Institute for Health and Welfare (THL), VTT, University of Helsinki, University of Kuopio |

[23] Publications at the highest profile journals

**Directed self-assembly** was intended for projects that are related to self-assembly and control at the nanoscale. Self-assembly is a universal property created by molecular structure and, to a certain extent, also by atomic structure. Positive interaction forces direct the relative orientation of molecules or atoms without any additional directioning.

There are two kinds of self-assemblies, namely intramolecular (e.g. in protein folding) or intermolecular (e.g. in creation of a micelle). Self-assembly is among the basic phenomena in nature as most biological processes are based on it. It increases the organisation of a system, but because the intermolecular forces are non-covalent, the created organisation is dynamic and self-correcting. Through directed self-assembly self-organisation processes can be realised systematically if the interactions between molecules are properly known. Self-assembly can act as a builder of system components, and in that sense enables the creation and utilisation of nanosized either non-covalent dynamically acting or covalent non-dynamically acting systems.

**Functionality in nanoscience** differs considerably from that at macro and microlevel. Miniaturisation of a functional unit to a scale of 1–100 nm or a function scale reduced to within a few nanometers has opened totally new possibilities to apply nanoscale processes. Numerous biological and chemical phenomena are occur at the nanoscale, and there is optimal utilisation of functional processes at the nanoscale in nature, which has evolved over billions of years. The goal of this thematic area is to target research in nanoscale functional processes with the aim of understanding, designing and creating nanoscale functional units to be used in different processes such as transfer, storage, transport, fault-healing, and reorganisation of information and energy.

**Properties of single nanoscale objects** are the foundation of nanoscale processes. The research in this thematic area focused on the investigation of these nano-object properties. Structural changes occurring in a nano-object (e.g. conformational changes in an enzyme) or storage of information/energy as well as transfer to another nano-object are all important basic processes in nature. The small size of the nano-objects can also be a problem. Possible harmful interactions of artificial nanomolecules and nanoparticles with biological material are consequences of the properties of nanoparticles .

The focus areas of the **Tekes FinNano programme** were defined preliminarily to be: innovative nanostructured materials, nanosensors and actuators and new innovations within nanoelectronics. In practice, the research topics were classified under the following themes:

- Electronics and photonics
- Surfaces, chemicals and materials
- Life sciences
- Forest products
- Tools and instruments

As can be seen, these topics are applied research by nature. In addition, the variety within the project topics was considerable owing to the large number of individual projects as well as focus on applied company-related projects.

## 4.4 Finnish nanotechnology sector in figures

The economic environment for nanotechnology is formed through demand and the supporting mechanisms. Nanotech Finland[24] presents the Finnish nanotechnology business environment focusing on commercial development driven by industry needs (including the electronics sector, forest cluster, chemicals and materials, and nanobiotechnology and diagnostics) and interdisciplinary science as a source for innovations (including materials, electronics and photonics, nanobiotechnology, and tools for nanotechnology).

It should be noted that in the analyses summarised below, the nanocontent, i.e., the extent to which the companies utilise nanotechnology in their products, has not been elaborated in detail. Nanotechnology is a cross-cutting discipline, and precise nano-specific figures cannot be obtained in practice.

According to the analysis of the Finnish nanotechnology survey of 2008[25], the nanotechnology sector in Finland exceeded EUR 300 million in 2008. Furthermore, the size of the nanotechnology sector is estimated to reach EUR 1,300 million 2013. The na-

24 Nanotech Finland (2010)

25 Spinverse (2009)

notechnology sector/GDP in Finland was estimated in 2009 to increase from 0.2% in 2008 to 0.6% in 2013[26]. Globally, the nanotechnology sector/GDP is estimated to grow from 0.3% in 2008 to 3.2% in 2013.

A survey on the operations, challenges, and funding of companies developing and utilising nanotechnology in Finland concludes that there are currently 202 active Finnish nanotechnology companies compared to 61 in 2004[27]. Of the companies operating currently, 65 had commercial products or processes in 2008 (compared to 27 in 2004). Most of the companies utilising nanotechnology operate in the chemical industry, information and communications technology, or in the health and wellbeing sector.

Exports accounted for 60% of the industry's revenue. The industry employs almost 3,000 people (compared to 300–400 in 2004). By 2013, it is estimated that the industry will grow to EUR 1.2 billion and will employ 11,000–12,000 people. The fastest growth in the Finnish nanotechnology business in 2008–2013 is taking place in the ICT, health, and energy sectors. The global economic downturn and the slowdown of global demand for nanotechnology products are going to have some adverse effects on the Finnish nanotechnology sector. Forest, metals and mechanical engineering, construction and services sectors are likely to take the strongest hit. The main challenges facing Finnish nanotechnology companies are a shortage of risk finance and qualified manpower, and intellectual property rights (IPR) issues.

In 2008, private investments in nanotechnology were for the first time greater than public investments. The industry received public funding worth EUR 38 million, industry investments were EUR 56.6 million and venture capital funding EUR 9.5 million. Total investments increased by 33.6% compared to 2006. Nanotechnology investments were focused on the chemical industry and materials, information and communications technology, and the forest industry.[28]

In the background interviews of the evaluation it was found that many companies that might benefit from nanotechnology hesitate to use nano materials or nano-based solutions in their products. The reasons are unclear, but most likely they are related to inadequate knowledge about the possibilities of nanotechnology and to a perception of the high risks related to nanotechnology due to, e.g., lack of standards and legislation.

## 4.5 Nano-relevant public innovation organisations

In the Finnish public innovation system, the main roles are played by the Ministry of Employment and the Economy (MoEE), and the MoE. General guidelines are drawn up by the Research and Innovation Council. The Council, chaired by the Prime Minister, advises the Government and its Ministries in important matters concerning research, technology, innovation and their utilisation and evaluation. The Council is responsible for the strategic development and coordination of Finnish science and technology policy as well as for the national innovation system as a whole. The Council has recognised nanotechnology as one nationally important area in 2006[29] and 2008.[30]

Under the MoEE, the main R&D and investment funding is targeted through Tekes, which is the biggest funding agency for research, development and innovation in Finland. Every year, Tekes finances some 1,500 business research and development projects and nearly 600 public research projects at universities, research institutes and polytechnics. The annual funding budget of Tekes is approximately EUR 0.5 billion.

Tekes has organised or participated in the organisation of two nanotechnology-related research programmes, whic are evaluated here. In addition, Tekes has arranged direct funding for nano-related research and development in companies. Besides the nano programmes, funding for the nano sector has been allocated within business sector-specific programmes, such as Potra-, PINTA, ELMO, COMBIO and NEOBIO. With respect to the na-

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26 Spinverse(2009)
27 Spinverse (2009)
28 Spinverse (2009)
29 SCT (2006)
30 SCT (2008)

notechnology business, an important tool in Tekes is the funding targeted at SMEs. Other instruments somewhat relevant to nanotechnology and nanoscience are

- The Foundation for Finnish Inventions
- Seed Fund Vera[31] (a nation-wide seed fund for enterprises in their initial stages)
- Finnish Industry Investment[32] (a government-owned investment company whose mission is to promote Finnish business, employment and economic growth through capital investment)
- Finvera (a specialised financing company owned by the State to provide its clients with loans, guarantees, venture capital investments and export credit guarantees)

The network of Strategic Centres for Science (abbreviated as SHOKs), Technology and Innovation is organised through the MoEE. It offers top research institutes and businesses a new way of engaging in close, long-term cooperation. In these Strategic Centres, businesses, universities and research institutes can agree on joint research plans, which are geared at solving the challenges of practical application by businesses within a 5–10-year timescale. Six Strategic Centres are currently in operation: Forest Cluster (Forestcluster Ltd), Information and Communication Industry and Services (TIVIT Ltd), Metal Products and Mechanical Engineering (FIMECC Ltd), Energy and the Environment (CLEEN Ltd), Built Environment Innovations(RYM Ltd), and Health and Well-Being (SalWe Ltd).[33] There is no Strategic Centre, or SHOK, in operation for nanotechnology, as nanotechnology is regarded as a cross-cutting competence area that enables innovation in all key clusters of Finnish industry.

On the regional level, the MoEE coordinates the National Centre of Expertise (OSKE) Programme. It is a special fixed-term Finnish Government programme to utilise the international-level expertise in Finland's regions. The cluster-based model aims to increase regional specialisation and to strengthen cooperation between the Regional Centres of Expertise. The Nanotechnology Cluster Programme (Nano-OSKE) includes the Centres of Expertise in Helsinki, Jyväskylä, Kokkola, Mikkeli, Joensuu, Oulu and Tampere. Within the Centres of Expertise the programme is based on the strengths of each region and on cooperation between companies, universities, research institutes and science parks. The technological core of the nano-OSKE consists of nano- and microtechnologies and future materials based on them. The key application areas in the Nanotechnology Cluster Programme include the electronics and electrotechnical industry, the mechanical engineering industry and metal refining, the information technology sector and health technology, the forest industry, the chemical industry, the plastics industry, the construction industry, and energy and environmental technology applications.[34]

The roles played by the SHOKs and OSKE programmes during the various stages of (nanotechnology) business development can be described as illustrated in Figure 3. The OSKE Nanotechnology strategy states that the OSKE Nanotechnology Cluster Programme focuses more on the more advanced stages of business aspects in the life cycle of new products than do the SHOK centres[35]. In the business sectors not covered by the SHOK centres, the OSKE Nanocluster programme may focus on earlier stages of business development.

Other regional structures include the Centres for Economic Development, Transport and the Environment that foster regional development by implementing and developing government activities in the regions.

The Finnish research and education system is governed and funded by the MoE. It consists of universities, polytechnics and research facilities. The Academy of Finland is the prima-

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31 An example of Seed Fund Vera operations is a recent investment in a company manufacturing nanoparticle filters (see http://www.finnvera.fi/fin/Finnveran-esittely/Tiedotteet/(newsid)/1473 [in Finnish])

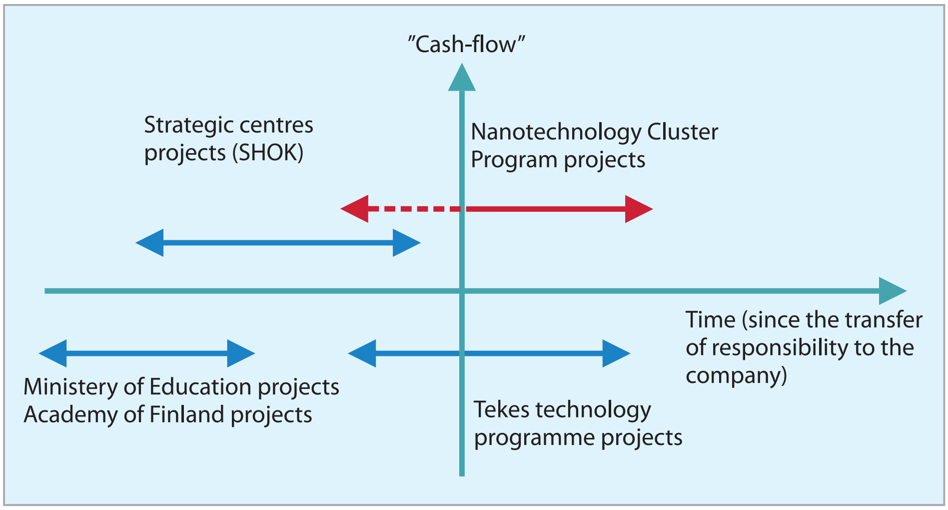
32 It should be mentioned that the company just signed an agreement with the Russian Corporation of Nanotechnologies on a Finno-Russian nanotechnology investment programme.

33 OSKE Nanotechnology (2007)

34 OSKE Nanotechnology (2007)

35 OSKE Nanotechnology (2007)

**Figure 3. The roles played in the life cycle of new products or businesses by the OSKE Nanotechnology programme.**




ry basic research funding agency in Finland. The Academy funds research annually with roughly EUR 300 million, which accounts for 16% of government R&D spending. Universities are independent public organisations or foundations, whereas polytechnics are run by municipalities or private parties. The MoE funds the universities and polytechnics from the State budget. It is important to note that the universities are independent and autonomous actors.

In summary, nanotechnology is driven and supported with the existing tools and instruments. There is no separate Finnish political agenda to define or support nanotechnology as such. The field has been recognised and policy actions such as the programmes evaluated here have been taken, but the support builds itself on existing instruments. Nanotechnology is seen as one enabling technology among several.

## 4.6 Social nano environment

### General

There are a number of social and societal questions related to nanoscience and technology, such as

- Impacts of nanotechnology on educational needs
- Nano-related risks and their control
- Organisational, regional and global impacts of new technologies
- Conception and acceptability of nanotechnology

In the following, we elaborate on the first two aspects.

### Nanoscience education

Novel research, technologies and production processes require novel approaches to education. Nanosciences necessitate the synthesis of research methods in physics, chemistry and biology. Since the innovation, value and production chains from basic research to applied research, prototyping, intermediate products and final products are long, comprehensive knowledge comprising in-depth business know-how as well is required. The educational needs concern not only university students but also vocational and polytechnic education as well as continuation education for people already in employment.

Today, nanoscience education is offered at a number of Finnish universities. For example, Jyväskylä University's Nanoscience Center provides cross-disciplinary bachelor and master's programmes and participates in the National Graduate School in Nanoscience. The students are provided with a cross-disciplinary education, consisting of both regular and intensive courses in all major subdisciplines of nanoscience and nanotechnology. In vocational schools and polytechnics, the role of nanotechnology in education is less pronounced. Nanotechnology enters education as a part of traditionally structured studies.

At the moment, commercialisation and business-related education and studies are only loosely coupled to scientific studies. This holds not only for nanoscience but for other paradigms in Finland, too. Some separate courses and summer schools are arranged, but the activities are not systematic.

In the interviews of the evaluation, some concerns on the depth of nanotechnology education were raised. Careful balancing between the generalistic nano education and targeted in-depth learning of specific issues was seen as very important.

### Finnish nano attitudes

Nano technology and science have been subject to endless public debate. The most important nano-related public concern is – without question – the aspect of nanosafety. This is justified in the sense that there are, at least in some nanoscience and technology areas, still some uncertainties and questions in relation to nanosafety. Also, the suitability of existing test methodology for assessing health and environmental exposure is still being assessed and developed[36]. It is also well known that the present legislation on the subject does not take all the issues into account. The prevailing opinion is that separate nano-related legislation is not considered necessary; instead, existing legislation should be reviewed and modified accordingly to take nanomaterials into account.

Worldwide, some NGOs[37] have taken a critical attitude towards nanomaterials, but in Finland the discussion has had quite a low profile. Nano-related reportage (printed and electronic publications, television, radio) has been monitored by Tekes' FinNano programme coordination. Most of the reporting on nanoscience and -technology has been neutral and informative and just under 10% has had a negative tone. Negative reporting has related almost exclusively to safety aspects, increasing slightly during the period 2006–2009[38]. Typical of and common to the negative nanosafety discussion and media attention has been the lack of a deep knowledge of the facts and risks.

Another relevant nano-related attitude pertains to nano hype. In the recent past, nano was seen as the answer to everything, and financial expectations, especially, were high. According to the interviews and document analysis, the hype seems to have been replaced with more realistic expectations. The nano concept itself has gradually become a part of everyday life through incremental improvement of products, as there have not been any real "killer applications" for end users and mass markets.

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36 OECD (2010)

37 see, e.g. www.foe.org

38 Internal media monitoring by Tekes FinNano coordination

# 5

# Micro cluster analysis

In this section we present the results of the micro cluster analysis described in section 2. The themes of the micro clusters were decided by the evaluation steering group, and individual contents of the clusters were negotiated with programme managers and persons in charge.

As reported earlier, one micro cluster was assigned to the Nanotechnology programme, two to Tekes' FinNano programme, one micro cluster to the Academy's FinNano programme, one to the MoE's funding, and one to funding cooperation between the three simultaneous programmes. In addition, one micro cluster describes the development path of Nanohybtonite, a Finnish nano innovation product consisting of a carbon nanotube reinforced epoxy resin.

For each micro cluster, project selection criteria, the analysed projects, and main findings are reported. The reporting structure varies slightly according to the micro cluster target, as some adaptations in the methodology were needed.

## 5.1 Selection of Nanotechnology programme projects

### Project selection

Projects for further study within the micro cluster analysis were identified and selected based on the results of the programme evaluation[39]. Some projects were identified as successful especially in terms of initiating a wider cooperation platform, whereas others were successful in terms of commercialisation potential. Five research projects were selected for further study within the micro cluster analysis. The projects covered different universities, research groups and fields of research in the field of nanotechnology and the research themes of the programme. The selected projects, main research organisation of each project, sources of funding and responsible persons are collected in Table 4.

The analysis was performed by interviewing the persons in charge of the selected projects. The interviews were carried out in April 2010. The interviews covered the contents of the project and their direct and indirect results, but also the later development path of the research themes and groups, cooperation platforms and innovations initiated within the research projects of the Nanotechnology programme.

### Main findings

Generally, the Nanotechnology programme was acknowledged by the interviewees as being a timely initiative to respond to the emerging field of nanotechnology and ensure that Finland is among the first countries to address the issue[40]. The programme was seen as positive in terms of increasing awareness about the field of nanotechnology in the Finnish research community and encouraging research teams to enter the area. This was also one of the objectives of the programme. It was also pointed out by the interviewees that investments on world-class research infrastructure are of fundamental importance in this field. Investments, however, require continuity of funding in certain thematic areas, and the programme was regarded as a positive enabler in this respect. Another positive aspect of the programme according to the interviewees was the fact that in

39 Yu and Ziegler (2000)

40 Japan was a forerunner in the area and initiated a national nanotechnology programme in 1994.

**Table 4. Selected projects from the Nanotechnology programme, main research organisation of each project, persons in charge, and sources of funding.**

| Project & Research organisations | Short description |
|---|---|
| Low-dimensional semiconductor devices based on nanotechnology; VTT Microelectronics Centre | The project developed a maskless selective fabrication process for InGaAs quantum wires; studied 0-dimensional systems using strain-induced, quantum dots; fabricated and characterised silicon quantum point contacts and fabricated light emitting Si/SiO2 superlattices and fast sub-100 nm MSM detectors. |
| Single electron transistor and new lithographic methods; Helsinki University of Technology, Low Temperature Laboratory | This research project had two goals. The first was to develop new AFM-based lithographic techniques for making nanodevices in the 1–20 nm size range. The second was to increase the operational frequency of metallic single electron transistors. |
| Technology for Molecular Computing and Colour Research and Biomaterials for Information Processing ; University of Joensuu, Lappeenranta University of Technology | The main objectives in the project were to do basic research in molecular computing and electronics; study biomolecules usable in opto-molecular computing; define basic optical and photochemical properties of chosen molecules; demonstrate variouscomputing functions using most potential optically active molecules; build a prototype system for colour vision based on biomolecular components and study computational models for protein based colour vision systems. |
| Superbright microcavity light emitters; Tampere University of Technology, Optoelectronics Research Centre, Tampere University of Technology | The objective of was to develop RC-LEDs for visible and infrared wavelengths for polymer optical fibre applications. |
| Coulomb blockade thermometry and NIS techniques; University of Jyväskylä | The initial goal of this project has been to develop Coulomb blockade thermometry to be a commercially compatible instrument. |

the programme funding criteria it was understood that development of new products and commercial applications in a field like nanotechnology require more time than the lifecycle of one research programme or research project (which last up to three years).

It was also commented by several project representatives, that many of the fields of research in the programme were not entirely new. It was more of a question of providing a new common "umbrella", nanotechnology, under which many more traditional research themes, like material physics, gained increasing and novel interest among the funding bodies and the industry. The common "umbrella" also provided a platform for increased cross-disciplinary cooperation.

The concept of the programme, co-funding of research by Tekes and the Academy of Finland, was generally acknowledged. Especially the concept of the Tekes-funded part of the programme was considered very successful, as it was considered well positioned to bridge the gap between basic and applied infrastructure-intensive research. This was also one of the original objectives of the programme. The concept of funding research without having industrial funding as a prerequisite was acknowledged by several interviewees. Involvement of Tekes and industrial boards in the projects which were very close to basic research was also considered successful by some respondents, especially in terms of stimulating the researchers to focus also on possible applications of the developed technology and on nurturing close relationships to the industry.

It was also mentioned by several interviewees that generally EU funding is often more applicable to the needs of the nanotechnology field than many of the national funding instruments. This is based on the fact that nanotechnology research is by nature long term : the time span from basic research to applications is long, and the eventual applications might be very different to those initially ideated. The EU programmes were considered by some interviewees as being positioned more between basic and applied research and as providing longer term funding and larger funding volumes than national funding instruments, and thus better support for the nanotechnology field. It was also mentioned, that EU programmes provide a good platform for carrying out multidisciplinary research. Often in nanotechnology different fields of research such as physics, chemistry and biology must be applied simultaneously. Some research groups had parallel EU funding at the time of the nanotechnology research programme. However, it was also emphasised that all available funding channels are highly necessary in order to maintain the required critical mass to carry out experimental world-class research in the field of nanotechnology.

In most of the selected projects the research themes initiated in the Nanotechnology programme have continued and evolved to date. In a couple of cases the funding provided by the Nanotechnology programme was a starting point for a new research area, which has grown substantially during a period of 10 years. In these cases, especially, funding from the Nanotechnology programme was mentioned as having served as a springboard to apply for other competitive funding sources internationally, too, and further develop the research group.

Some of the selected projects also led, already during the programme or in the later phases of development, to the creation of start-up companies. Especially successful among the selected projects and partners in the creation of start-up companies has been the Optoelectronics Research Centre (ORC) of Tampere University of Technology. The project "Superbright Microcavity Light Emitters" within the Nanotechnology programme had a indirect impact on the founding of the Centre, and is thus one of the positive factors behind the development of the optoelectronics cluster in the Tampere region. Currently, the spin-off companies of the ORC in the field of optoelectronics employ more than 100 people.

One of the original objectives of the programme was to foster new, interdisciplinary interactions leading to new, unforeseen opportunities for creativity and innovation. Several interviewees pointed out that one important advantage of national research programmes is improved national networking. One example of success in initiating new long-term research partnerships in the field of nanotechnology is the cooperation between Aalto University, the University of Jyväskylä and VTT Chemical Technology. Many interviewees also pointed out the importance of international networking, where the nanotechnology programme was an important catalyst both directly and indirectly.

Since the nanotechnology programme, the initiated research themes and the associated research groups have utilised many funding sources. the Academy of Finland's Centres of Excellence in Research (CoE) were one important source of funding, which was mentioned by several project representatives. International funding is utilised increasingly, too. As mentioned earlier, the EU Framework Programmes and the European Space Agency's (ESA) funding were mentioned as sources which provide more continuous funding in the sense that, e.g. the chaining of projects is easier than in Finland.

Some FinNano projects were also directly linked to the selected projects and research partners of the nanotechnology programme. It was also mentioned by some respondents that since the Nanotechnology programme there have not been any possibilities to utilise Tekes funding, as research in the nano field is still very close to basic research and it is difficult to fulfil Tekes' prerequisites for industrial funding.

One interesting case study within the micro cluster is the development path of the Low Temperature Laboratory of Helsinki University of Technology (currently Aalto University). The research project "Single Slectron Transistor and New Lithographic Methods" within the Nanotechnology programme was actually an important starting point for later developments of the research group, which are described below as a case study.

CASE STUDY

## Low Temperature Laboratory of the Helsinki University of Technology[41]

In early 1990s, the Low Temperature Laboratory of Helsinki University of Technology focused on two main research themes: research on ultra low temperature physics and neuromagnetic brain research. In both of these research themes the laboratory was at an internationally highly recognised level. Later on research on nanophysics, or investigation of the properties of nanoelectronic systems, emerged as a third important research theme for the laboratory, and the Nanotechnology programme played a role in this development, too.

The research on nanophysics was initiated by Professor Mikko Paalanen, who had previous experience in electron lithography technology from the USA (at the ATT Bell laboratories). Professor Mikko Paalanen brought the related know-how first to the University of Jyväskylä (Applied Physics Group) at the beginning of 1990s, and then to the Low Temperature Laboratory of Helsinki University of Technology, where he was appointed as a Director in 1996 when Academy Professor Olli Lounasmaa retired. The nanotechnology-related research at the University of Jyväskylä was also further developed based on this initial starting point in the field of electron lithography and Single Electron Transistors (SETs). At the University of Jyväskylä the research evolved and became multidisciplinary, involving the fields of biology and chemistry as well.

The project "Single Electron Transistor and New Lithographic Methods" within the Nanotechnology programme was started in 1997 in cooperation between the Low Temperature Laboratory and the University of Jyväskylä (Professor Jukka Pekola). VTT was also involved in the project. VTT was experienced in studying lithographic methods in their cleanroom facilities and also had experience in sensor research. VTT was involved in the consortium as an end user for the single electron transistors. The research project had two goals. The first was to develop new AFM-based lithographic techniques for making nanodevices in the 1–20 nm size range. The second was to increase the operational frequency of metallic single electron transistors. One challenge in the development work was the required low temperatures for the sensors. The functioning single electron transistor technology at the University of Jyväskylä was based on aluminium-aluminium oxide technology. A new additional approach within the project was to utilise nanoparticles produced by VTT Materials Technology (Professor Esko I. Kauppinen) in AFM-based lithography. The project resulted in a successful demonstration of single electron transistors and the inception of a new research theme within the Low Temperature Laboratory. The project resulted indirectly also in other new initiatives, which emerged later on, such as carbon nanotube research. In this sense, the funding provided by the programme was an essential enabler for later developments of the Low Temperature Laboratory and also in a wider context for nanotechnology-related research in Finland. The single electron transistor has also later been further developed for metrologic purposes, where it might provide a future standard for electrical technology. This development is currently being exploited in cooperation with Mikes – Centre for Metrology and Accreditation.

The nano group of the Low Temperature Laboratory is presently investigating fundamental quantum phenomena in nanostructures using low temperature and electronic transport measurements. In both normal and superconducting nano samples, the quantum mechanical wave character of the electrons and their Coulomb repulsion are leading to new phenomena, which the group is striving to utilise in new sensor/amplifier applications. Currently the Low Temperature Laboratory and VTT are also running a common Centre of Excellence in nano components (CoE in Low Temperature Quantum Phenomena and Devices). The Centre of Excellence was launched in 2006, and will operate until the end of 2011. The main focus area of the CoE is on components of

41 Based on interview of Professor Mikko Paalanen.

nanoelectronics, and it is based on the research lines which were initiated in the Nanotechnology programme. Probably the most important indirect result of the project within the Nanotechnology programme is the launching of the CoE.

Overall, the development of the Low Temperature Laboratory from 1996 to 2009 has been very positive. In 1996, the research of the Low Temperature Laboratory was divided roughly 50/50 between brain research and ultra low temperatures, the overall volume being 55–65 man-years. In 2009, research is divided 50/30/20 between brain research, nanophysics and ultra low temperatures, the overall volume being 80–85 man-years. The nanophysics research theme has established a strong position in the laboratory over a period of almost 15 years. The same period of time was required also for the other research themes, ultra low temperatures and brain research, to become world class.

Cooperation with the research partners within the nanotechnology programme project has also continued to date. Professor Kauppinen has re-directed his aerosol research on carbon nanotubes, and the cooperation is still on-going. Professor Pekola is currently based at the Low Temperature Laboratory.

Commercial products have not yet been produced based on the results of the research project. However, one start-up company has resulted from the nano efforts at the Low Temperature Laboratory. The company, BlueFors Cryogenics Oy Ltd, was established in 2007. The company delivers easy-to-operate refrigerators for nano researchers. The products have been delivered globally to several Universities, e.g. in the USA, Russia and Switzerland. In Venture Cup 2008 the company was awarded a best entry from Helsinki University of Technology. ■

## 5.2 Hybtonite™ technology innovation value chain

The Hybtonite™ technology innovation value chain was selected as one target area for the micro cluster analysis. The Hybtonite™ technology micro cluster differs somewhat from the other micro clusters, which are mostly based on the analysis of selected research projects and allocated funding within the nanotechnology-focused research programmes. The basis for the selection of Hybtonite™ technology as one target area of the analysis was the inclusion of an in-depth case study on an entire innovation value chain, all the way from research up to commercialised product applications.

The analysis of the Hybtonite™ technology innovation value chain case study was performed by interviewing a few key people in April 2010 in order to collect in-depth information on the development path of the case. The interviews were also supported by a study of publications, interviews and other available background material on the case. The main results are presented below in the form of a case study.

CASE STUDY

## Hybtonite™ – Development path of a commercialised nanotechnology-based research innovation

Hybtonite™ is a trademark for a nanotechnology-based material innovation, carbon nanotube reinforced epoxy resins, which are used in numerous end user applications. The innovation is based on research which was led by Professor Jorma Virtanen and carried out at the Nanoscience Center of the University of Jyväskylä. The research focused on the field of carbon nanotubes, and dates back to the beginning of the 2000s. The innovation behind the Hybtonite™ technology originated from the main line of the research. The actual research project aimed at developing sensor applications for carbon nanotubes. The key to the Hybtonite™ technology, the dissolving process for carbon nanotubes, was discovered in the project. Furthermore, potential applications for the dissolving process were then ideated and patented as spillover innovations by the individual researchers. One of these innovations was the Hybtonite™ technology, which is based on dissolving and subsequent covalent bonding of carbon nanotubes in the epoxy matrix. Covalent bonding of carbon nanotubes leads to substantial improvements in the strength properties and conductivity of the resulting epoxy material.

Further development of the Hybtonite™ material and production process was carried out by Nanolab Systems Oy, a start-up company established by the researchers. The main focus area of Nanolab Systems Oy was, however, nano particle synthesis technology and instruments for drug research. The carbon nanotube-based operations (Hybtonite™ technology) of the company were developed together with partners. The ice hockey stick manufacturing company Montreal Sports and their chemical provider SBT Oy, which was active in the composites market, were the first development partners. Excel Sports was also involved in developing Hybtonite™ technology together with Nanolab Systems, with the aim of developing novel floorball stick applications. The material enabled improvements in the strength properties and thus substantial reductions in the weight of the stick.

Commercialisation of the Hybtonite technology™ was later carried out by Amroy Europe Oy. Amroy Europe Oy was established in 2005 by combining the carbon nanotube related operations of Nanolab Systems with the operations of a development partner, SBT Oy, a chemical provider for the composites industry. By utilising the existing customer base of SBT Oy, several new product applications for Hybtonite™ technology were launched already within Amroy Europe Oy's first year of operation . Montreal Sports Oy launched the first commercial application of Hybtonite. In January 2006 Montreal Hybtonite™ hockey stick "Nitro" was voted number one Nano product in the world, at the world's biggest nanotechnology trade show in Tokyo, Japan. During 2007 approximately 100 customers tested Hybtonite in their own processes and several leading companies (for example Easton, Peltonen and Baltic Yachts) chose Hybtonite™ as the material for their most advanced products. The sales and manufacturing volumes of Hybtonite™ increased rapidly during the period 2005–2008. Sales volumes totalled EUR 10,000 in 2005, EUR 272,000 in 2006, EUR 700,000 in 2007 and EUR 1,500,000 in 2008.

Today the original innovators of Hybtonite™ technology, Pasi Keinänen, Antti Valtakari, Kimmo Kaila and Jorma Virtanen are still at Amroy Europe Oy, in operational management and on the Board. The company was recently honoured by Frost & Sullivan with the European Technology Innovation Award in Nanocomposites for 2009. Currently Hybtonite™ as a material component is utilised globally in products like ice hockey sticks, wind mill blades, skis, and hunting arrows, to name a few application areas. The current market areas of the company include wind, sports, marine, civil, oil and prepregs and resins. The production capacity of the company is in Finland 4,000 tonnes and 10,000 tonnes in China.

The funding of the development and commercialisation process of Hybtonite™ consisted of several sources. The impact of Tekes was important in the form of a commercialisation loan, which was granted from the FinNano programme. The loan was utilised in marketing the Hybtonite™ product. Other sources utilised included venture capital funding and recently also EU funding from the EUROSTARS programme, which was applied for together with international partners.

In the commercialisation process of the Hybtonite™ technology a number of key steps can be identified. One bottleneck for the commercialisation of the technology was the availability and cost of the raw material, the carbon nanotubes.

Back in 2004 carbon nanotubes were really expensive. However, Bayer was identified as a new potential raw material provider of carbon nanotubes. Bayer was capable of providing carbon nanotubes in quantities and cost-efficiently, which enabled bulk applications for Hybtonite™. Co-branding of the product with the trademark Hybtonite™ was also an important step, which provided product differentiation and value for both partners. Branding of a product was carried out sufficiently early the commercialisation process, which enabled good differentiation from competing products in the novel, rapidly developing market.

Another key step in the commercialisation process was the selection and incorporation of several partners in the joint development and commercialisation of the Hybtonite™ technology. Partners with strong experience in customer application areas were highly valuable and accelerated the commercialisation process. The key competences of the application partners created a good balance with company's own core competence and cooperation, and sharing of information was mutually beneficial. Key partners had a strong existing customer base in the global marketplace, which made it a lot easier to penetrate the application markets with a new product.

As a result, the innovation was developed from laboratory scale into a commercial product in less than three years. In addition, there were several other key factors which enabled fast commercialisation into global applications. One key factor was, as always, having the right people with the right attitude in the right place at a right time. The key people possessed an entrepreneur attitude, and were willing to take a risk and start the company to further develop the innovation. They were also willing to share information with partners, which enabled an accelerated commercialisation process.

However, in addition to right strategic decisions, lucky coincidences also played their role in the case. The basis for Hybtonite™ technology, a successful dissolving process for carbon nanotubes, was actually discovered by chance. Bayer as a partner was also found by chance, during an unofficial chat in the corridor at a nano conference in Germany. ■

## 5.3 Surface and nanostructures projects in Tekes' FinNano programme

### Project selection

Nanosurfaces and nanostructures constitute a broad area that is currently under active research. The design of complex structures with novel properties has potential applications in many existing and emerging fields such as material science, optics, electronics and biotechnology. The bottom-up approach of nanostructuring relies on self-assembly to create structures on the nanoscale, which makes it particularly suitable for, e.g. coating and for many other uses in industrial applications.

In nanosurfaces and nanostructures micro cluster projects owned both by companies and research institutes were examined. The companies were either very small companies with only research and development operations or medium-sized companies with broader operational environments. Public sector projects were owned by VTT and Aalto University. The projects are listed and briefly introduced in Table 5.

### Main results and impacts of the micro cluster

In the nanosurface and nanostructure micro cluster new materials, processes and manufacturing technologies were developed with a broader set of properties and applications in, e.g., coatings, microsystems and optics.

Improved business conditions were considered as one of the most important impacts of the projects, both in the public and the private sector. In the private sector the possibility to expand the scope of in-house research was seen as highly beneficial; as there was no need for external subcontractors, potential IPR problems could be avoided. In the research sector new researchers were employed, and project work, diploma thesis and doctoral thesis opportunities could be offered for students. As a consequence it was estimated in the interviews that the number of publications, patents and new inventions was in some projects even higher than in other Tekes projects carried out by the interviewees. In the private sector the impacts on employment figures were mainly less significant. Also, increased knowledge within the partner companies in new materials and manufacturing techniques was seen as

**Table 5. Projects included in the micro cluster and their short descriptions**

| Project & Research organisation | Short description |
|---|---|
| HighPerformance Ceramic Coatings for Extreme Conditions; VTT Microelectronics Centre | Novel ceramic coatings were developed using new material combinations, allowing less porous coatings with improved fracture toughness and higher resistance to corrosion and erosion. The project was implemented in cooperation with HUT and the Chinese research centre SINANO, as a part of NAMI-cooperation. |
| ALD Nanocoatings for Industrial Applications; Helsinki University of Technology, Department of Micro and Nanosciences | The objective was to develop coatings that could be used in microsystems, optics and other applications. The nanoscale accuracy of ALD in layer thickness and composition enables entirely new and cost-efficient solutions. The project was a continuation of the ALDUS-project (also in Tekes' FinNano programme), in which the research in ALD technology was initiated at TKK Micronova. |
| Industrialisation of Functional Nanocomposites; Valukumpu Oy | The objective was to develop and improve a specific plastic product so that it can be used for casting thinner structures which also have better air permeability. |
| Nanoscale Anti Fingerprint Surface Treatments and Coatings for Polymer and Metal Substrates; Savcor Face Group Oy | Chemical gas-phase coating processes were developed that can be used to layer functional coatings. The main application is in protection of plastic lenses. |
| Manufacturing Devices for Functional Equipment; Beneq Oy | Various laboratory-level manufacturing technologies (e.g., ALD – Atomic Layer Deposition and nHALO) for functional surfaces were industrialised. Also production equipment for different surface modification applications was developed. |

highly important for the entire operational environment.

Impacts on sales are only relevant for private sector actors. In Beneq Oy the project resulted in significant positive impacts on sales, whereas other companies in this micro cluster experienced only small or nonexistent impacts. In Beneq, as a result of the project and the increased sales 10 new people were employed annually. At best new products were developed, which enabled entry into entirely new product markets. New business opportunities were identified both in the public and the private sector. Increased awareness of the risks and health issues of nanotechnology, especially in the customer companies, was seen as one of the major drivers that would deliver new business opportunities in the future, too. Moreover, entirely new research areas were identified, for example possibilities to broaden diagnostic applications in biopharmaceutics.

At a more general level, increased credibility and a strengthened scientific reputation were considered as impacts of the projects that provided new clients and cooperation partners both in Finland and internationally. Increased credibility has further provided opportunities to apply for non-traditional projects internationally. Overall, the people in charge of these micro cluster projects considered that the Tekes FinNano programme had reached all the Finnish actors in the field of nanotechnology and connected experts, research institutes, companies and other stakeholders in an effective manner.

## Programme benefits

All the actors considered increased networking and finding new partners as one of the major benefits of belonging to the Tekes FinNano programme. In the public sector the help from Tekes with international partners, e.g. with contract issues, was seen as a considerable benefit. Through the programme, research and investments in nanoscience have increased substantially, which has further increased both scientific and application know-how. The programme has provided new business opportunities which might not have been identified otherwise. Increased awareness of different application possibilities was seen as one of the major drivers. On the whole, through increased public awareness of nanoscience and its application possibilities, Finland and the whole world has awakened to the vast potential nanoscience has to offer. The impact will be felt not only by scientists but also more broadly in many new industry sectors, most likely providing new business opportunities in the longer term, too.

According to the interviewees, co-operation between different projects in the Tekes FinNano programme was limited, if not non-existent. Conferences were considered the only route that to some extent encouraged knowledge transfer between different projects. Only one of the private sector projects in this micro cluster had more extensive cooperation with another project, in which the combination of two different technologies was studied. In many cases, the lack of cooperation, especially, between company projects is understandable, as the main task for a company is usually the project itself.

### Programme and funding cooperation benefits

Most of the interviewees understood that there was some sort of cooperation between Tekes and the Academy of Finland. The cooperation took place mainly between the funding agencies and was not very visible to the field. Promoting cooperation and communication between Tekes and the Academy of Finland was considered useful by most of the interviewees: The private sector, however, did not perceive the benefits this kind of cooperation would offer companies. Two projects in this micro cluster were partly based on the nanotechnology programme of the 1990s.

The Centre of Expertise programmes (OSKE) were surprisingly foreign both to the private and the public sector actors. The projects had no connections to OSKE activities, with one exception, where Nano-OSKE had played a small part in the project. Promoting cooperation with Tekes programmes and OSKE programmes was again beneficial, however any hands-on improvement proposals could not be offered. The actors were even more unfamiliar with the Strategic centres (SHOK centres). The SHOK centres were seen more as “playgrounds” for large companies, where small and middle-sized companies, and particularly the research institutes, had little or no possibilities to exert influence.

For the public sector actors the funding cooperation with the MoE had a significant impact on research quality and on obtaining scientific results. Improving the infrastructure has widened the range of available research methods, increased cooperation with other research groups and provided better chances to get additional funding from other sources. New equipment has also had a positive impact on education, furnishing the opportunity to provide new kind of education, knowledge and project possibilities for students and young scientists.

## 5.4 Photonics projects in Tekes’ FinNano programme

### Project selection

Nanophotonics is the study of the behaviour of light at the nanometer scale. It is a combination of two multidisciplinary fields, photonics and nanoscience, which both can be considered highly important in enabling technologies in the future. The use of nanostructures enables the production of materials with new optical properties and possibilities to design novel photonic components. It is expected that nanophotonics could revolutionise a wide variety of markets such as transport, telecommunications, computing, life sciences, manufacturing and information.

In the photonics micro cluster five projects were owned by research institutes and one project by a private company. More company representatives were preliminarily planned to be interviewed, but it appeared that some of the chosen companies were working with applications connected only loosely to the theme of the micro cluster. Thus, the corresponding research institute partners of these projects were interviewed instead. The projects are listed and briefly introduced in Table 6.

### Main results and impacts of the micro cluster

In the photonics micro cluster new laser technologies and manufacturing technologies, e.g. nanoimprint lithography, were developed, with application use in, e.g. conductor components, sensor applications and biomaterial- and nanostructures. Results that were not originally set as objectives were also achieved in some of the projects.

The programme had positive impacts on employment in some of the public sector projects, as they hired 1–3 new researchers, whereas in some projects there was no need for new recruiting. In the private sector the project merely enabled current employees to be retained.

Impacts on sales were relevant only for the private sector actor. The sale of one new product developed in this project has been going well since its launch, and even higher sales figures are expected in the future with another new product. With respect to the public sector projects, new product launches were made in some of the partner companies and further development are ex-

**Table 6. Projects included in the micro cluster analysis and their short introductions**

| Project & research organisations | Short description |
|---|---|
| Nanophotonics; Optoelectronics Research Centre, TUT | A new fabrication technology, nanoimprint litography (NIL) was developed for different nanophotonic applications. NIL was applied in the fabrication of hetero-epitaxial semiconductors and metallic nanostructures. Surface and particle plasmons in metal surfaces and nanostructures were investigated for bio-sensing. The first single-mode distributed feedback semiconductor laser fabricated by NIL was developed during this project, too. There were five research partners and altogether 11 industrial partners in this project. |
| Nanophotonics – Extension; Optoelectronics Research Centre; TUT | Semiconductor quantum structures for light emission at mid-IR wavelength range, nanoimprint lithography technology for realising single-mode semiconductor lasers and nonlinear waveguides were developed. The project also included the development of photonic nanowires and fibre Bragg gratings for various applications in fibre lasers. The project had three research partners and four industrial partners. |
| Novel nanophotonic devices based on ALD and Si-photonics; Helsinki University of Technology, Laboratory of Micro- and Nanosciences | New waveguide components were developed for Si-nanophotonic applications. The benefits of a Si-nanophotonic process developed in Singapore are combined with Atomic Layer Deposition (ALD) technology developed in Finland. Possible applications for the components are biosensors, chemical sensors and optical telecommunication devices. |
| Multiphoton biomaterial processing using ultrashort laser pulses; VTT – Technical Research Centre of Finland | 3D microscale shaping methods for biomaterials were developed using fast pulsed lasers. The objective was to obtain extremely fine resolution using inexpensive microchip and fibre lasers, and to build the software for efficient rapid prototyping from 3D CAD models of the structures. Industrial partners (Nanofoot Finland, Macrocrystal, Scaffdex) are further developing different industrial applications for these biomaterials. |
| Multiphoton biomaterial processing using ultrashort laser pulses; Scaffdex Oy | 3D biomaterial structures were developed for cell and tissue applications. An insert model was developed that works with the laser polymerised structures. |
| UV-LED Matrix for Photo Guided Bioplexing of Combinatorial Biochips; Helsinki University of Technology, Laboratory of Micro- and Nanosciences | Customised high density UV-led photo-inducable matrix formats were developed. They are used to synthesise and prepare photo-guided molecular arrays as combinatorial chips for bioplexing. |

pected to lead to commercialisation of new innovative products in the future.

In some projects of the micro cluster new business opportunities were even identified, whereas other projects were not so successful. However, entirely new research areas, were identified in almost all of the examined projects. This is of course more apparent owing the prevailing number of research institutes in this micro cluster. In new multidisciplinary research areas, cooperation between two entirely different fields of science was often seen as a major challenge that might slow down new innovations.

In this micro cluster the projects were seen as important drivers to enhance cooperation with other research groups and also in developing totally new cooperation networks. In one of the projects, the new international partner provided possibilities to do research and product development that could not have been done inside Finland. The projects also provided opportunities to apply non-traditional projects both in Finland and internationally. Most of the interviewees considered that the programme had reached the Finnish actors in the field of nanoscience in an effective manner. However, companies not operating specifically in the nano field but which, nevertheless, could be possible application developers, might have been somewhat excluded.

## Programme benefits

Increased networking and finding new partners was seen as one of the major benefits of belonging to the Tekes FinNano programme. In particular, creating new international cooperation with partners in, e.g. China and Singapore, was seen as an achievement of the programme.

All of the interviewees deemed the programme to have had considerable impacts on the research currently being done in nanoscience in Finland. Most of the projects, especially those conducted in cooperation with international partners, could not have been initiated or implemented without the programme. Moreover, most of the research groups might have been involved in something entirely different but for the FinNano programme.

The programme has positively influenced attitudes towards nanotechnology and increased public awareness about nanoscience and its application possibilities. Highlighting new business opportunities, which might not have been identified otherwise, was seen as one of the crucial benefits delivered by the programme. Also, thanks to the Tekes FinNano programme, it has been easier to focus the research, profile the research activities and further facilitate marketing to industry partners. The programme has provided a level of continuity in research and brought about new extension projects and opportunities to apply new projects both in Finland and internationally. None of the interviewees in this micro cluster had cooperation with other projects in the Tekes FinNano programme.

### Programme and funding cooperation benefits

Cooperation between Tekes and the Academy of Finland was not visible in the field, but it was considered worth promoting in order to further improve cooperation between research institutes and private companies. None of the projects in this micro cluster were based on the nanotechnology programme of the 1990s.

The Centre of Expertise programmes (OSKE) were fairly or entirely foreign both to the private and the public sector actors. The projects had no connections to OSKE activities, with one exception, where OSKE had helped in arranging new partners and funded conference trips. Promoting cooperation with Tekes programmes and OSKE programmes was, however, seen as beneficial. Only one of the projects had connections to Strategic Centres (SHOK). SHOKs were seen as unsuitable and too short-term for research activities and also more as "playgrounds" for larger companies, with no entry for small and medium-sized companies.

Funding cooperation with the MoE had a significant positive impact. Through improved infrastructure both research quality and quantity have improved considerably, and new equipment has provided the opportunity to do research that is scientifically more challenging and also more industrially relevant.

## 5.5 Sample of Academy's FinNano projects

### Project selection

The projects in the Academy's FinNano programme were organised basically in project consortia and each consortium consisted of 4–6 research groups. The consortia can be roughly divided into categories outlined in section 3.3. Of these, representative examples from the categories "nanoparticles and structures in life sciences and medicine", "material properties of nanodevices" and an example of an international networking project were drawn as described in Table 7. Since the emphasis in the evaluation is on positive learning, the selections were based on discussions with the Academy's FinNano programme manager and the steering group. Hence, it should be noted that these projects represent in some sense the best results and impacts of the programme when it comes to its added value[42].

The analysis was performed by interviewing a sample of persons in charge from the consortia. The interviews were carried out in May 2010. The interviews covered the contents of the project and their direct and indirect results, and the added value of the programme, as well as more general topics on the nanosciences in Finland.

### Main results and impacts of the micro cluster

All the projects in the micro cluster have produced a number of international publications, some with high impact factors, which is an indisputable sign of the quality of the results. For example, in the Funano project, experiments and mathematical models supported each other in an exceptionally interesting way, as the models predicted phenomena that were found in the experiments. In the Nanofridge project, a novel heat conduction mechanism was even discovered, and the PEPBI project holds a distant promise of commercialisation.

[42] Scientific results are not evaluated here.

**Table 7. Projects included in the micro cluster analysis and their short introductions.**

| Project & Research Consortium | Short description |
|---|---|
| FUNANO – Functional Nanoparticles and Devices; seven research groups in the University of Jyväskylä, Tampere University of Technology and the University of Helsinki | The Consortium focused on research on the electrical, optical, magnetic, and thermal properties of nanoparticles, nanotubes, quantum points, and fabricated nanostructutres. The consortium combined physical, chemical and technological knowledge to produce new information that can be used in existing and new practical applications of nanoparticles. Some applications are solar cells, optoelectronics components and detectors. One technological goal was to develop nanoparticle-based mass production methods for, e.g., the manufacturing of Grätzel solar cells or light displays on bending surfaces (see text box). |
| PEPBI – Enhanced therapeutic effects via intelligent peptide-loaded nanoparticles; five research groups in the University of Kuopio, the University of Oulu and the University of Turku | See case study. |
| NANOFRIDGE – Thermal effects in nanoscale superconducting junctions; One Finnish group in an international consortium, Helsinki University of Technology | A physical cooling system was studied. The ideas to use electronic systems for local cooling had come in earlier research. The idea was to build an easy-to-use locally cooling system that can be cooled to 0.01K by an electrical current. The prevailing idea is to trap the fast, "hot" electrons using suitable metallic-superconductor nanostructural joints. In principle, the research could produce cooling platforms for sensors and other components requiring deep cooling to operate. Since other similar cooling systems operate on different, less efficient principles, there might also be a commercialisation interest in the future. |

International big breakthroughs are still, however, in the future.

The results also have been disseminated in a generally understandable format in Academy magazines and at science brunches intended for journalists.

## Programme benefits

All of the interviewed group leaders deemed the programme to have had considerable impacts on the research currently being conducted in nanoscience in Finland. The groups within the consortia have cooperated during the whole project. For example, in the FUNANO consortium, samples made in at the University of Jyväskylä have been analysed at Helsinki University, and modelling work at Tampere University of Technology has been supported with practical results. In the PEPBI consortium, cooperation was very close as the

CASE STUDY

### Grätzel solar cells mimic photosynthesis

The Grätzel cell is a thin film solar cell-based photoelectrochemical system. Unlike semiconductor cells, dye-sensitised solar cells work with a principle whereby photons produce an electric current. In Grätzel cells, particles of TiO2, coated with a dye that absorbs at a wide range of wavelengths given off by sunlight, are placed between two electrodes in an electrolyte solution containing iodine ions. The cells generate electricity when the energy captured by the dye makes the electrons in the dye molecules jump from one orbital to another. The electrons then jump onto the TiO2 particles and diffuse towards one electrode, while the iodine ions carry electrons from the other electron to regenerate the dye. Grätzel cells offer very high efficiencies and the economics are promising because they are based on TiO2, a cheap and widely available material.

The cell was invented in 1991 and is named after the Swiss inventor Michael Grätzel. The cell is subject to vigorous research throughout the world. The materials in the cell are nanoparticles. Michael Grätzel was awarded the Finnish Millennium Prize 2010 for the development of the cell.

The cell has vast potential, e.g., in roll-to-roll production, but one of the current main problems is the lifetime of some thousands of hours at maximum. Grätzel cells were studied in the FUNANO consortium of the Academy's FinNano programme.

groups continuously exchanged materials and problems. The Nanofridge project has increased cooperation with the existing ERA-NET project members.

All of the interviewed consortia members agreed that Academy of Finland funding was essential for the project to succeed. With respect to the consortia, the application process forced the consortium to sit down and write a good research plan together. The fact that funding was received simultaneously for all the groups was also very important. Without Academy funding, the groups would have pursued different funding opportunities, and the outcome most likely would not have been as coherent as now.

For the Nanofridge project, the added value was different as the project was a part of an ERA-NET consortium, where the Academy of Finland also allocated the funding. All the significant European researchers in the topic were gathered under the same project. For the application to succeed it was very important that each participating group received national funding simultaneously. Cooperation had a significant role, as the groups helped each other to leave their comfort zones and search for new approaches. The content of the project is being carried out in the Microkelvin project, which is an EU funded integrating activity project that offers 4–5 year funding. The role of the Academy programme itself was negligible for the project.

It was pointed out by several interviewees that, although seeming large, the Academy of Finland funding boiled down to quite small amounts when divided over groups and time. In practice, the funding is sufficient for hiring

CASE STUDY

## PEPBI consortium – where cooperation truly pays off

Nanoscale can significantly reduce the toxicity of drugs, enhance their therapeutic effects and improve their dissolution properties in the body. Nanoscale drug delivery systems consist of a drug and a carrier. In polymeric nanoparticles, a drug can be entrapped or dissolved in the matrix or adsorbed on their surface, or a core drug can be surrounded by a shell. Further, drugs can be loaded into nanoparticles prepared from different types of mesoporous materials. When compared to simple drug formulations, nanoparticles increase the stability of drugs in physiological fluids, including the acid conditions of the stomach, and enable targeted and controlled drug delivery.

The PEPBI consortium was based on interdisciplinary approaches that combined pharmaceutics (one group), molecular medicine (one group) and physics (two groups). The physics groups developed aerosol methods to produce polymeric nanoparticles and fabrication methods to produce mesoporous silicon nanoparticles; the pharmacy group studied in vitro effects of these nanoparticles, and the molecular medicine group studied in vivo effects of the particles. In aerosol methods, dry nanoparticles are produced via droplet-to-particle conversion in gas-phase from the solution of a mixture of polymers and drugs. With mesoporous silicon nanoparticles, the drug molecules are loaded into the porous nanoparticles, whose size (2–50 nm) and the surface chemistry can be varied in relation to the size and chemical nature of the molecule. The porosity and pore sizes in porous silicon can be tailored with etching parameters.

The drugs studied in the PEPBI project were peptides. Specifically, peptides involved in the regulation of feeding were studied, and thus, these peptides might provide a way to treat obesity and the development of type II diabetes. Currently, clinical use of peptides is hindered by a variety of limitations, particularly their short in vivo activity duration and poor oral bioavailability. These problems may be solved by nanoparticles. Hence, already at this stage, the societal impacts of the research results are seen as significant. The consortium's topic is unique in Finland, and the scientific status represents a good international level. The research has produced a number of peer-reviewed journal articles, conference presentations and an international EU application consortium – unfortunately the proposal was not funded by the EU.

The consortium members themselves state that not all of the previously set goals and targets were achieved, since many new problems arose on the way. However, a big leap in the direction of the project targets has been taken. The main technical challenges at the moment include the ageing of nanoporous silicon particles and the clumping of aerosol particles. It might even be that the results could be commercialised within some years. It is often said that the consortia formed for funding applications are rather artificial and do not work together. Nevertheless, this consortium represents a true chain of knowledge, where rivalry in the consortium is at minimum and each participant obtains added value from the others. The factors explaining this are that the research focuses on a well-defined problem that can be divided into non-overlapping subproblems, but also the general attitude and social skills of the persons involved, especially the consortium leader, are important.

one part- or full-time PhD student. This may partly be the reason why some interviewees characterised their work as "learning the problems".

From a group leader point of view, the added value of the funding programme was marginal. At this stage, the researchers have strong international networks, and direct benefits from programme activities themselves were quite marginal, as expected. The seminars organised for graduate students, on the other hand, were mentioned as being very successful.

Much of the experimental work in the projects was conducted with the equipment procured with MoE nanoscience funding, at least in part. It is quite evident that coordinating the procurement with the programme funding decisions has been of great value.

## 5.6 MoE's nanoscience funding

### Project selection

The Ministry of Education allocated nanoscience funding to six universities in Finland during 2007–2009. The universities were the following: Tampere University of Technology, the University of Jyväskylä, the University of Joensuu, the University of Helsinki, Helsinki University of Technology and the University of Oulu. The total amount of the funding was almost EUR 23 million. More detailed information on the background and money allocation process has been described in section 3.3.

For the impact evaluation five universities (i.e. all that were funded, except the University of Oulu, which had received clearly less funding than the others) were scrutinised. Background information on the distribution of the funding sum within the universities was collected through a short e-mail survey and more detailed information on selected research groups/departments/centres was obtained by interviewing their leaders. The research groups/departments/centres for the case studies were selected so that they represented a variety of disciplines and funding applications.

### Funding description

#### Tampere University of Technology

During years 2007–2009 the MoE allocated EUR 3 million of the nanoscience funding to Tampere University of Technology. This funding was further allocated to the Optoelectronics Research Centre (EUR 600,000/year) and the departments of Physics (EUR 150,000/year) and Chemistry and Bioengineering (EUR 250,000/year). In the Laboratory of Chemistry, funding had been sought for the Photo-Group, which mainly used the sum to pay for equipment, but also for payment of salaries, travel and materials, etc.

The Photo-Group on supramolecular photochemistry has 15–20 workers and is headed by Professor Helge Lemmetyinen. The equipment purchased with the funding was for the group's primary needs, but it is also freely available for use by other researchers and is extensively used in education.

The funding has had a significant impact on the continuation of research started earlier, launching new projects and obtaining scientific results. The funding was strategically important for the research group, as it enabled one-time equipment purchases. Good infrastructure of a laboratory and evidence of successfully finalised studies increase the reputation and provide better changes to obtain additional funding from other sources.

The purchases were mainly essentials for the chemistry laboratory's basic infrastructure. Thus these purchases have also wider utilisation possibilities than just the supramolecular nanotechnology, which was the primary interest. The equipment has widened the range of available research methods and increased the capability for studying new phenomena. This has also increased cooperation. The group sees the purchases mainly as equipment enabling the group's research. However, the research area itself is such that one day commercial applications will be developed somewhere.

The funding has had direct impacts on the University as a whole, because its scientific reputation and position has strengthened through scientific publications produced by the group. Scientific research resulting in publications and dissertations means more funding for the University, too. The funding has also had an impact on the University's educational portfolio.

#### University of Jyväskylä

The University of Jyväskylä received EUR 4.75 million of the nanoscience funding during years 2007–2009. This funding was further allocated to the Nanoscience Center and departments involved. The sum was used to procure equipment, and to pay for new and existing positions, rents, education, etc. One of the new positions that were established was the five-year professorship in thermal physics. The thermal physics group is headed by Professor Ilari Maasilta (Department of Physics, University of Jyväskylä). The group has five post-doctoral researchers, five postgraduate students and several undergraduate students.

The professorship has been very crucial for the research group and has more or less provided the cornerstone for its continuation. The professorship has increased the group's visibility and may also help in acquiring new funding.

The nanoscience funding comprised altogether 20% of the total funding of the units in 2007–2009. The funding was of great importance to the nanoscience working environment at the University of Jyväskylä and it actually enabled many activities of the Nanoscience Center.

A new professorship, as such, can also affect the whole nano sector, as professors have more possibilities to influence strategic planning and education, at least at departmental level. It also ensures that education in this area is available at the University of Jyväskylä too.

**University of Joensuu**

During 2007–2009, the MoE allocated EUR 1.4million of the nanoscience funding to the University of Joensuu, which forwarded the funding to the Department of Physics and Mathematics. The sum was used specifically for equipment but also in part for new and existing positions, travel as well as materials. One major purchase was a new electron beam pattern generator, for which partial funding had been allocated already in 2006. All the equipment purchased with the funding is free available for use by all researchers at the department.

All the procurements have supported the research carried out in the department and thus its core competence. The purchases were planned so as to be are strategically important for research and the acquisition of new research funding and employment of new researchers.

The purchases have improved the research environment and research competence and made new openings possible. Also the quality of work has improved.

Cooperation has increased through the utilisation of the equipment, especially in Finland, and has also increased the publication cooperation with external partners. The improved quality of the laboratories, as well as the increased number of publications has enhanced the visibility of the department.

The funding has strengthened the position of the University and the whole area (including the University of Applied Science and the local companies) in the nano sector. It is now the only place in Finland where the whole lithographic production chain of nanostructures is available. The entity is now becoming big enough to apply for EU funding. To further strengthen the infrastructure, the University has decided to build a separate unit for infrastructure bringing together equipment from the Joensuu and Kuopio campuses.

**University of Helsinki**

The MoE allocated EUR 3 million of the nanoscience funding to the University of Helsinki during 2007–2009. The funding was further allocated to seven faculties or other units by the HENAKOTO group (a development group for research and education in nanoscience). One of the faculties that obtained funding was the Faculty of Biological and Environmental Sciences, where the funding was allocated to the Finnish Centre of Excellence (CoE) in Virus Research headed by Professor Dennis Bamford. His laboratory represents about half of the CoE and has approximately 20 employees.

The MoE's nanoscience funding (about EUR 100,000 altogether) was used in the Virus Group to pay for salaries and support infrastructure. The funds were used to build and improve an optical trap – a world-class device used for manipulating single molecules. Its construction was started already earlier, but needed further funding. The optical trap is located at the Department of Physics, in the laboratory of Professor Edward Haeggström (University of Helsinki). The project has been an opening for cooperation between two disciplines: biological sciences and physics, and aim to nanoscale manipulations down to a single molecule level.

This project has produced several scientific publications as well as academic degrees. The MoE's nanoscience funding was crucial for carrying out the work further, although other funding sources were used as well.

Overall, the obtained funding has been crucial to improving the research infrastructure and research competence and has made new research openings possible for the research group. There are also commercially available optical traps, but their performance does not match the one built. The trap built at the University of Helsinki has already attracted international attention. It is sought after in EU infrastructure projects and could also be of commercial value.

### Helsinki University of Technology

The MoE allocated EUR 5.54 million of the nanoscience funding to Helsinki University of Technology during years 2007–2009. Its Centre of New Materials, which is an umbrella organisation for several laboratories and departments, was assigned to make a proposal of funding distribution. The Centre gathered applications from all the applicants and had them ranked by external experts. Based on the ranking, a proposal was made to the rector on the funding distribution. The method was considered smart, transparent and well-coordinated. Funding was distributed to a number of laboratories and departments, and the Centre for New Materials has tracked the use and impacts of the funding.

One of the largest funding recipients was Micronova, the Centre for Micro and Nanotechnology. Micronova is a joint research centre operated by VTT Technical Research Centre of Finland and Aalto University. The organisations and equipment are separate, but the cleanroom facilities are common. The cleanroom and the equipment are operated by 21 people. Unlike many cleanroom facilities in Sweden and Denmark, there are no specific process assistance personnel. In the following, we concentrate on Aalto University's contribution to Micronova.

Today, the equipment of Aalto University in Micronova is worth approximately EUR 7 million, of which some 80% is nano related. VTT has about three times more equipment, but less is related to nanoscale. Investments in new equipment total EUR 0.4–0.8 million annually. At the moment, there are 110 registered cleanroom users, and the cleanroom facilities contribute to more than 100 peer reviewed publications yearly.

Altogether, the MoE's nanoscience funding for Micronova was a little less than EUR 1 million. Approximately EUR 0.6 million of the funding was used for nanofabrication equipment, with which various nanostructures can be built and analysed. This is equivalents two thirds of the value of the equipment.

Although the MoE's nanoscience funding contributed only to some 20% of the total nano-related funding its impact, especially at the beginning, was significant. If MoE nanoscience funding had not been obtained, the nanofabrication equipment would have not been purchased. Since the equipment is among that used most regularly at Micronova, it is evident that a number of scientific results would not have been obtained without the funding. Furthermore, nearly 10 projects from Tekes' FinNano programme and three project consortia from the Academy of Finland's FinNano programme used the equipment. Had the equipment not been procured, much of this work would have been done elsewhere or would not have been done at all. In summary, the impacts of the MoE's nanoscience funding in this case have clearly been significant, and the synchronisation with programme funding has clearly provided added value.

## Summary and key findings

The MoE's nanoscience funding during the period 2007–2009 was allocated to universities as a part of the normal funding based on their applications. It turned out to be quite laborious to track down the flow of the funding sums starting from the Ministry and ending, for example, with the actual purchase of equipment in a research group. The further allocation of the funding varied from university to university, and at least in part, the universities seem to have used the funds in a manner that differed from that indicated in the funding applications. Moreover, the system, how decisions were made, varied from one university to another.

The overall impact evaluation of the funding was challenging. Originally the idea was to evaluate the impact of the funding on specific research groups that had been funded. It was, however, noticed that the amount of money that was available for a certain research group varied greatly and the sums were also used in a different manner, e.g. some used it to pay for new or existing positions and some for large equipment procurement. Thus, it is natural that the impact also varied to some extent. However, in general, the following aspects were identified as having improved: **v**isibility, collaboration, working conditions, and working possibilities. The funding was also seen as having a positive impact on future application rounds, for example, through improved infrastructure. Overall, the funding was seen as very positive – if not even crucial for the work.

It must be stated, however, that a key factor explaining the success of the funding was the constant lack of research equipment funding in Finland. Each and every funding agent, even companies, suppose or state that the equipment must be procured separately, but for procurement there is no clear funding system. Both the funding offering and equipment procurement are somewhat uncoordinated.

On the demand side, applying for funding and justifying the importance of research has become an everyday task for professors and researchers in universities. On the supply side, the available funding to develop infrastructure and equipment is scarce. Thus, the budget of the universities serves as the primary source for equipment purchases. In some universities there is a fixed amount of money allocated for equipment maintenance and development. In many universities, however, the annual investments for equipment do not even keep pace with the annual depreciation, and significant additional investments are needed just to retain necessary maintenance contracts. This easily results in an unpredictable, random funding environment where everybody obtains something without clear focal points.

To decrease the need for both research institutes and private companies to purchase similar equipment, some universities contract or lease services related to equipment use. However, based on the interviews, the income obtained from leasing is quite insignificant, as many of the companies cannot or are not willing to pay the actual expenses. Moreover, it is important to keep in mind that these kinds of services should not place too much pressure on or take resources from the main task, academic research, especially if there is no full time staff to take care of the equipment.

Using funding allocated for equipment purchase to lease equipment time from other research institutes and pay the travel expenses, etc. was also considered a possible way to increase the utilisation rate. In large international research centres and universities leasing activities are common and there are even specific guest rooms allocated for visitors. These kinds of activities could be utilised more widely in Finland, too.

## 5.7 Funding collaboration

### Project selection

Some research institutes and departments host groups that have received funding from all of the three programmes: MoE nanoscience funding mainly for instruments and equipment, and research funding from the Academy or Tekes. On the other hand, some equipment procured with MoE nanoscience funding was used in the FinNano projects of Tekes and the Academy.

As reported earlier (see section 3.5), there was some formal and informal funding collaboration between the FinNano programmes themselves and the MoE's nanoscience funding. In this microcluster the aim was to investigate the effects of funding cooperation. The focus was on how MoE-funded equipment was used in FinNano projects run by Tekes and the Academy and what were the benefits of simultaneous funding. Three locations were selected for interviews:

- University of Joensuu, Department of Physics
- Tampere University of Technology, Department of Chemistry and Bioengineering
- Helsinki University of Technology and VTT Technical Research Centre of Finland – Micronova

Project managers from different Tekes and Academy of Finland projects which utilised the equipment in these locations were interviewed.

At the University of Joensuu, MoE nanoscience funding was used to obtain an electron beam writer, and several Tekes and Academy projects have applied the device. At Tampere University of Technology, a mass spectrometer with instruments for various chromatographic applications was the most important equipment purchased with MoE nanoscience funding, and was used in 14 different projects that were set up by either Tekes or the Academy of Finland. Micronova used MoE nanoscience funding to obtain nanofabrication instruments, which were used in several Tekes and Academy projects.

### Main results

Here we concentrate on the cooperation between the Tekes and Academy FinNano programmes and MoE funding. The effects of funding cooperation in the application phase of a programme can be divided as follows:

1. Preventing unintentional overlapping of research funding
2. Increasing networking, cooperation and efficiency by appointing possible partnerships on the basis of funding applications
3. Redirecting applications between the funding bodies to make a better match
4. Increasing the coherence of funding

By coherence we mean funding of science, technology and innovation so that it is allocated with a view to enhancing cooperation between research groups in order to obtain specific results in a specific time frame. This may also mean deliberate and intentional overlapping of funding.

Of the above effects of cooperation, the first takes place mainly behind the scenes, whereas the three latter effects are visible to the field.

In the implementation phase of a programme, cooperation is usually manifested in the from of joint activities for the participants and in coordinated public relations. In the postprogramme phase, joint evaluation is a common method of cooperation.

Based on the background interviews, the cooperation in the programme management was indeed able to reduce overlap in the application phase and to match applicants to form consortia. Here, the effects within funding bodies are more important than between the bodies, since the profiles of the funding bodies are very different. However, redirecting applications especially between Tekes and the Academy was considered very important.

Clearly the most significant added value from the collaboration in the application phase has been the coherence of funding. Information sharing from Tekes and the Academy to the MoE has made it possible to target nanoscience funding in a way that greatly improves the research group's ability to proceed with the projects. Via the collaboration it has been possible to carry on the intended research with the intended equipment in the intended schedule. For the projects that used equipment procured using MoE nanoscience funding, this was considered significantly important, and implementation of the project without the funding would have become much more difficult and in some projects almost impossible.

From the infrastructure point of view, MoE nanoscience funding was seen as one of the rare sources in Finland that enables research institutes to purchase more expensive and special equipment. On the whole, the improvement of the laboratory equipment infrastructure that was achieved through MoE nanoscience funding was regarded as very important in enhancing the quality of research and also in the future when applying, e.g., from Tekes or the Academy of Finland.

Overall, instrument and infrastructure funding is problematic in Finland. Research funds are directed towards research work, and Tekes, for example, specifically forbids the use of its funding for instruments. Consequently the MoE's nanoscience funding has been of great importance also for Tekes and Academy funded projects. However, active funding collaboration between the funding organisations was not apparent to the interviewees – the cooperation had taken place behind the scenes. Finland's laboratory infrastructure and related issues are discussed in more detail in section 7.1.

Cooperation during the execution of the FinNano programmes through joint meetings and other activities has taken place, but the added value seems to have remained small. The programmes, the target audiences and their goals are perhaps too different to provide sufficient added value for the participants. Furthermore, the programme activities in the Academy's FinNano programme were consciously kept to a minimum. Joint national and international public appearances during the programmes , on the other hand, seem to have been a good way to increase visibility and social impacts.

A clear problem with the collaboration is that it is somewhat loose; at the moment it is a good practice in organisations based on personal relations and personal activity at all levels. All three programmes could also have been implemented without any collaboration, but most likely the results would have then had far fewer impacts .

# 6

# Main findings

## 6.1 Introduction

In this chapter we summarise the main findings from the micro cluster analysis. Where appropriate, these findings are also supplemented by the results from the background and stakeholder interviews.

## 6.2 Programme evaluations

### Nanotechnology programme

When the Tekes and Academy Nanotechnology programme was launched, nano research was only just getting started in Finland. Although the programme was small, it provided a strong kick start to Finnish nano research and related business area. The goals of the programme were to build basic knowledge and research capabilities and were highly relevant in this respect. Based on the evaluation materials it can be stated that the goals were largely attained. Although even then some of the topics had already been studied, the programme brought the fields under a common denominator and increased nano-related knowledge.

During the 1980s and 1990s Tekes had many other similar types of programme in other areas, e.g. electronics[43], which could generally be called "technology catch-up programmes". The driving force of these programmes was the general finding that the field was developing rapidly throughout the world, but Finland was not part of the development. These programmes were then central to building technological competence within the fields in Finland. At the time they were regarded as very successful, and even now long-term impacts can be recognised. The same holds for this programme. As described in the micro cluster analysis, innovation chains, companies, research groups and professional research careers have stemmed from the era of the programme.

One relevant factor explaining the success of these programmes in general is the fact that they were catch-up type programmes for a small number of applicants. Thus, no difficult strategic choices were required. Essential relevant programme contents were identified by examining foreign progress and by extending existing research, e.g., in material physics to the micro and nanoscale. The programme scope of the era was quite technological, and value chain-related issues, like business opportunities, commercialisation and IPR problems, which often look complicated from the researcher point of view, were avoided.

The programme evaluation report was published in 2000[44]. The evaluators considered the programme structure and administration to be good. In particular the flexibility, both in organisation and management (streamlined reporting requirements) and in industrial funding, were found to be key reasons for the innovative and enthusiastic research atmosphere within the programme. In addition, the possibility to carry out interdisciplinary research in a field between basic research and applications jointly funded by Tekes and the Academy was seen as highly important. Programme services and international cooperation were not evaluated.

### Tekes' FinNano programme

Unlike the Nanotechnology programme, Tekes' FinNano programme was launched at a time when the technology policy had already been replaced by an innovation policy, and the technological goals and targets of programmes were replaced by a variety of targets ranging from technology and research to commercialisation and business opportunities. Consequent-

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43 Raivio et al. (2007)

44 Yu and Ziegler (2000)

ly, the Tekes FinNano programme goals are stated differently and according to Tekes' guidelines. As an interesting remark on the speed of evolution it may be stated that during the programme, Tekes strategic guidelines changed three times. Despite this, the goals have been in line with them.

The goals of the programme were quite broad and formulated in a way that makes it difficult to say how the goals have been met. After the Nanotechnology programme there had been no coordinated national funding for nano-related research and business, and it is evident, that the Tekes FinNano programme has been very important for Finnish nanotechnology business and research. Consequently it has strengthened the research and enhanced commercialisation. The long-term internationalisation activities in the programme and the link to EU activities have been reported as successful in the evaluation interviews, but in the field of researcher mobility the outcomes appear to have been modest. This is by no means the fault of the programme; it has been noted in many other evaluations and appraisals that internationalisation development and researcher mobility in general are difficult issues in Finland.

One aspect in achieving the goals is clearly problematic, and that is how to get companies to see the opportunities in nanotechnology. From the evaluation interviews it can be seen that at the moment many companies are either unaware of the possibilities of nano-related products or technologies, or consider the risks related to the use of nano-related products or technologies too high. It is clear that a single programme which has networked only nano-related companies cannot solve such issues alone. In a broader sense, this is a major obstacle in commercialising nanotechnology, and actions in the innovation policy field are needed.

Programme coverage was good – altogether more than 100 companies were involved in the Tekes FinNano programme. Compared to the total number of nano- related companies in Finland, this is roughly one half[45]. Nevertheless, the competition in company funding was somewhat modest, as many companies were involved through joint funding of research projects. Both large companies and SMEs were present in the programme.

Programme services were in the main commended by the programme participants. In particular, the long-term persistent and focused trips to China (instead of single trips to various locations) were seen as a good way of setting up commercial channels. On the other hand, the need for programmatic networking services, although excellent, was partly questioned, as in the opinion of some participants, SMEs were regarded as being strongly networked via Nano-OSKE and large companies through SHOKs. This may mean that the nano field is now organised in Finland in such a way that further openings in networking activities are becoming less necessary.

The mid-term evaluation[46] of the programme was implemented as a self evaluation. The evaluation reported good ratings from the programme participants in terms of directing the programme and added value. At the time of the evaluation, the projects had mainly produced new knowledge and inventions, but there were also some commercialisation results already then.

On average, the main results of the programme lie in the increase of mutual knowledge of the participants. Some new business opportunities were created and a number of new research openings were seen, but mainly the added value of the programme was built on funding, increased networking and finding new partners. In this sense, the programme was a good example of a typical successful Tekes programme.

### Academy's FinNano programme

For the Finnish nano research field, the Academy's FinNano programme was an even more central source of funding than was Tekes' FinNano programme for companies. Academy funding – especially that through Open Call Grants – has in many cases been regarded as "fund and forget". Networking activities and other programme services have often been kept at rather a minimal level. The underlying assumption is that those who receive funding from the Academy are already fairly networked in their own field and would not obtain much added value from such activities. Consequently, the keys to programme success stem largely from the selection process.

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45 Spinverse (2009) reports on roughly 200 nanotechnology companies in Finland; Nano-OSKE has listed 450 nano-related companies, but it is not clear how closely the companies are related to nano business.

46 Koponen et al. (2008)

The objectives of the programme were set rather generally, and it is not very meaningful to try to assess the achievement of the objectives in detail. Actually, most of them fulfilled already by the scientific participant selection process. Some objectives, however, such as advancing cross-disciplinary approaches, promotion of responsible nanotechnology development and promoting international cooperation have required strategic choices in the project selection phase which reflect themselves in the selection of project consortia. In addition, since the programme participants are distinguished members of the scientific community, their actions will most likely fit those objectives which deal with improved knowledge and the advancement of science.

The research programme strategy of the Academy of Finland[47] outlines the principles for the programme's instrument usage. The programme aims to renew the research and to produce new interdisciplinary information. The programme is also aimed at promoting internationalisation and acting as a forum for international cooperation. It is hoped that the programmes will produce scientific and social impacts. When comparing the goals of the programme and these outlines it is evident that the objectives are in agreement with the intentions of the Academy of Finland.

Academy funding also serves as merit for the applicants, which means that the incentives for applying for funding are high. Hence, the programme covers the field fairly efficiently in the application phase. The downside is that once the funding is decided, those who are excluded often lose interest in the programme; the programme becomes a networking tool only for the participants. In this respect, maximising the number of participants would be justified, but as the budgets are limited, this immediately leads to quite small funding amounts.

The programme consisted of a single application round. Several application rounds in later years might have helped in refocusing the programme – if needed – and in maintaining a broader interest within the scientific community.

As mentioned above, the programme services in the programme were fairly minimal, but this was a conscious decision. On the other hand, the seminar organised in the programme for junior researchers who do not necessarily have sufficient networks yet was mentioned on several occasions as a good example of networking.

Consortia formation and work in the consortia have been regarded very important in value adding. Of course some consortia may have been formed for the application purposes only, but such consortia are often recognised already in the evaluation phase and, as demonstrated in previous sections, true cooperation and added value from this also ensue. For existing consortia, coherent and simultaneous funding for a joint activity was a major booster. Instead of creating a separate flow of applications to separate funding agencies, the groups in the consortium were able to fully concentrate on the project work.

The funding model – common for many Academy programmes – must be criticised somewhat. When divided among groups and over four years, the money per group becomes rather small – in some cases it is not even sufficient to hire a full-ime graduate student. This reinforces the trend towards small groups operating separately in Finland and inhibits the growth of larger groups with a more critical mass. Although large research consortia may not be the best solution in all fields of research, certainly units with sufficient funding are desirable.

If the funding is used to hire doctoral students, as is often the case, publications and degrees are produced, but international breakthroughs remain random on average. It is essential to ask whether more precise focusing – clear making of choices – would have produced increased scientific impacts.

Overall, in the light of these case studies and other materials, the Academy of Finland's FinNano programme seems to have been successful. Based on the micro cluster interviews, the programme has had a well coordinated management and has achieved optimum coverage and brought research groups together. On the whole, the results and participant satisfaction are excellent.

### MoE's nanoscience funding

The intentions of MoE nanoscience funding were good and the preparation process very thorough, and the funding itself has been considered very welcome. The most important factor explaining the success is, however, the

47 SA Research Programme Strategy 2009

constant lack of equipment funding in Finland. Most funding organisations forbid the use of funding for equipment, and often funders assume that equipment will be funded by someone else. Funding mechanisms support neither rational procurements nor collaboration. Suggestions to improve equipment funding mechanisms are outlined in section 7.1.

The funding mechanism itself was slightly problematic. The main challenge was that basic university funding is not designed to be an instrument that can be used for guiding contents or research emphasis. Consequently the procedures for applying funding, distributing it, using it, and reporting usage and impacts were not well-defined, and therefore different approaches for further distribution of funding were taken, tracking was not evident and impact assessment not clear. It needs to be noted that despite the criticism, everything has been done in accordance with existing rules.

The funding and steering mechanisms of the universities by the MoE have changed simultaneously with the change in the legal status of the universities. The State is still the main funding source of the university sector enabling the MoE to continue to steer the universities. The steering process has shifted towards a more holistic approach, where higher education institutions strengthen their profiles and strategies and the Ministry is responsible for making the strategies fulfil the national goals of the higher education sector. Consequently, the funding model presented here has been gradually scaled down.

## 6.3 Funding cooperation

As reported earlier, there was formal and informal funding cooperation between the FinNano programmes and the MoE's nanoscience funding. For example, project applications were sent from Tekes' FinNano programme to the Academy's FinNano programme, and joint seminars were organised. On the other hand, the Tekes and Academy programmes' management participated in the MoE's nanoscience funding decision-making with information about ongoing or starting projects in the programmes.

The Academy of Finland, Tekes and the ministries have cooperated previously, too, in order to enhance the use of funding instruments. Based on the interviews, the cooperation has been mainly sporadic and has been based on personal contacts. Official or organised cooperation, especially at the operative level, has been limited, which also became apparent in this evaluation.

Cooperation between the programmes and the MoE's nanoscience funding was considered very important. The system prevented several overlapping funding decisions and enhanced the programme participants' possibilities to implement the projects. In the future, such coordination efforts are warmly recommended.

The programme cooperation was rather invisible to the programme participants. One could ask if the Academy and Tekes should have implemented a joint programme by putting all the funding in a single pot that would have been distributed, but there are several reasons why this might have complicated things. Firstly, the organisations do not have flexible enough mechanisms to implement joint programmes such as these. Secondly, the added value of such a programme might not have been worth the effort, since the Academy's funding clients and Tekes' funding clients are somewhat different. Mechanisms like these could, however, have resulted in closer cooperation between research and companies, which might have had a positive impact on the reluctance of the companies to apply nano-related technologies. The effects would mainly have concerned only the participating companies. Most importantly, the cooperation has strengthened the FinNano concept abroad and in public.

The guidance mechanisms of the MoE to guide the universities have changed. Instead of discipline-specific issues, it is more and more important for the MoE to coordinate the goals of different funding organisations, and the development of funding instruments. This development would perhaps be reflected in the information gathering cooperation, too. One existing example to strengthen the information gathering cooperation is the RAKETTI[48] initiative.

The contact points between the Nanotechnology programme and later programmes were surprisingly modest. However, the people behind the projects were largely the same. One interpretation for this is that the field is established but the technologies and research problems have evolved in just a few years so much that the themes

[48] RAKETTI is a common information management development initiative between the MoE and the universities. RAKETTI is coordinated by the Finnish Centre for Scientific Computing (see raketti.csc.fi).

that were relevant 10–15 years before the present programmes have become obsolete.

## 6.4 Programme impacts

As reported above, the Nanotechnology programme has had a strong impact on the building of Finnish nano research competence. Now, after more than 10 years, it may be stated that the impacts have been fairly permanent, both in the fields of research and in business. The most significant impacts relate to knowledge and competence accumulation. Although the programme had little impact on education or teaching, it laid foundations or reinforced many research centres. The programme also networked Finnish researchers.

Since the focus of the Nanotechnology programme was mostly on technology learning, significant direct innovative or commercial breakthroughs were scant, although after a certain incubation period some did appear. The programme was a little introverted in the sense that it had only a limitedimpact on the social aspects. On the other hand, the programme gathered the participating organisations under the nano umbrella.

With respect to the present programmes, only short-term impacts can be described. Firstly, as the programmes have, in practice, been the only sources of coordinated national nanoscience and technology funding, their value to the field has been enormous in terms of funding. The funding has accelerated product development and offered a chance for research groups to advance their knowledge of relevant issues. In some cases, the funding from the programmes served as a springboard to apply for other funding sources and further develop the research group.

Concerning the added value of the programmes, the research and business fields are now better networked than before the programmes. It may even be stated that the programmes have given life to Finnish nanoscience and -technology, and there are some concerns about what will happen when the programmes end. The programmes have enabled cross-disciplinary views and research projects that would not have been successful in other funding systems. It remains to be seen what will come out of these projects. In the evaluators' view, cross-discipline broad-minded new openings are one of the keys to Finnish success, and the programmes have succeeded very well in supporting this.

The programmes have increased the credibility of the nanoscience and technology field. For researchers, Tekes funding, especially, acts as a strong support when research results are presented and offered to the industry. Academy funding, on the other hand, serves as merit for the research groups which helps in further funding.

The programmes have somewhat increased public awareness of the nano concept, but the increase has not been ground breaking. It now seems that as the nano hype is fading away, public discussion, too, on nanosafety and risks is on healthier, more objective ground.

# 7
# Nanofuture

## 7.1 Potential challenges for the Finnish nano innovation system

In the evaluation, several general challenges in the Finnish nano innovation system were identified. The nano innovation system here refers to the innovation environment in which research and business is being done. In the following, we describe some of the challenges. Again, the challenges are based on data collection and various interviews.

### Client companies avoid nano

Firstly, for some reason many client companies hesitate to use nano products or technologies. The companies either do not see the possibilities and relevance, or they consider the risks still too large. One possibly contributing factor is the lack of standards and legislation. This is a major obstacle for nano-related business growth; nanotechnologies are enabling technologies that require applications to realise their potential. On the other hand, it must be stated that so far nanotechnology has not been able to demonstrate real killer applications.

Long-term research cooperation is needed to find suitable application areas, and when such areas are identified, speed and agility are needed to utilise the findings.

### Founding hi-tech companies is difficult in Finland

A general remark in the evaluation data gathering was that one of the biggest challenges in creating more business is the difficulties relating to setting up companies. In general, it is thought that entrepreneurship is undervalued and despite all the political agendas, public opinion is negative. The society does not share the risks related to, e.g., employing people, and growth without extensive funding is impossible.

For high-tech start-up companies, further problems arise. The business capabilities and competences of researchers are modest, which means that knowledge about basic issues like IPR, funding, management, leadership and strategy may be lacking.

For companies already in the nano market, the main problems are internationalisation and business logic. The funding of hi-tech companies is inflexible and there are too few clients in the Finnish market for hi-tech companies, and internationalisation is essential. For larger companies in the field, the main problems are starting to be the knowledge shortfall in Finland and internal communications.

### How to combine education and business life?

From the educational point of view, there is a strong culture in many universities and research groups against anything other than science. Although this culture is now changing slowly, becoming an entrepreneur with a scientific education is, in practice, a sheer impossibility at the moment. Currently, the number of PhDs being produced in Finland far exceeds the number of academic positions available. Researcher tenure track development is a strategic goal in the universities at the moment, the objective being to broaden the concept of an academic career. Still, the demand for entrepreneurship education does exist. For example, the Centre for New Materials in Aalto University organises an annual short course on entrepreneurship, and there are always more participants than can be admitted.

It might be possible to look the problem from another angle: how would it be possible to support academic meriting while already working? Nanotechnology companies need PhDs, too. At present, working while completing a PhD is almost impossible.

There should be flexible mechanisms to support this; perhaps in the future we will see MBA-type degrees reversed so that the extra formal qualification is related to the substance.

### Fragmented funding – fragmented research?

In particular, the Academy's funding within the FinNano programme was rather fragmented. The fragmented nature of the funding also supports the hiring of graduate students. For the group leader, this is useful, as graduate students produce publications and dissertations, the number of which constitutes one factor in future funding allocation. This, however, is hardly the way to systematically make an impact in science on an international level . Furthermore, such funding models support the fragmentation of research: even now there seems to be numerous small research groups operating more or less separately. Overlaps appear, and the overall efficiency of the research work at national and even university level is perhaps not as good as it could be.

It may well be that the rivalry between the research groups is not a sufficient mechanism to steer research. National research funding bodies have a long tradition of not interfering with research contents and guidelines, but could it be that we have come to a point where more coordinative actions – choices – are needed? In any case, from the standpoint of efficiency and communications, larger research groups might be propitious, and funding with suitably designed incentives would be an effective tool to promote increasing the size of research groups.

### Challenges of cross-disciplinary work

Nanoscience is a cross-disciplinary issue. Often, these cross disciplinary niches are considered very important sources of new findings and innovations. It is sometimes argued that traditional research evaluations may have difficulties in pinpointing the most prominent new cross-disciplinary openings. Referees and evaluators often represent only one side of the research and provide evaluations singlehandedly. In a broader context the issue is that new research initiatives contain risk, and a relevant question is the risk attitude of the funding agents. The present programmes are a good example of how cross-disciplinary projects succeed and produce fruitful cooperation.

In order to survive in global competition, this is a tendency that should be strengthened. Finland should do things – at least in part – differently. Accordingly, this means taking more controlled risks.

### Finnish equipment procurement discourages cooperation

A modern, adequate research infrastructure is a necessity for essentially any science in universities. Some fields of science, such as physical nanosciences, are highly dependent on heavy research equipment and, as such, it is impossible to do high quality research using merely project funding.

The interviews discovered that the equipment procurement process seems to promote inefficient procurement and use of equipment. Firstly, the equipment is usually procured with specifically allocated money that cannot be used for anything else, such as travel expenses related to using common equipment. Secondly, there are no depreciation requirements for the equipment. This means that in the years following the procurement, there are no capital costs related to the equipment. Thirdly, there are no systematic accountability requirements and follow-up mechanisms.

Centralisation was considered one solution that could be used to increase the utilisation rate. In the interviews, Micronova and ORC were considered examples, where centralisation has been effectively executed to ensure higher utilisation rates and overall effectiveness. However, because the research institutes in Finland are fairly widely dispersed geographically, it is quite impossible to centralise all of the basic equipment.

Because there is not sufficient funding in Finland to purchase all the equipment that needed, prioritisation – making choices – was seen as necessary. At a high level, a general plan on infrastructure funding and prioritisation in Finland has been published, including the current state and a roadmap[49]. In the report, nanosciences are presented via the Micronova centre of VTT and Aalto University. With respect to nanosciences, it is recommended that Finland reinforce national coordination and division of tasks in nano-

[49] Moe (2009)

science and nanotechnology and utilisation of international research infrastructures[50].

The cooperation between Tekes and the Academy of Finland with various equipment funding actors was seen as crucial. When it is decided to invest to a specific area of science, this information should be distributed so that the necessary funding can be provided during the entire lifecycle, including funding for equipment and risk funding for fledgling companies.

## 7.2 Recommendations

### General

Nano-related targeted and coordinated funding in Finland is now coming to a temporarily halt. Both FinNano programmes are ending and the MoE's nanoscience funding ended already in 2009. In the light of this evaluation, the decision of Tekes and the Academy not to continue nano funding per se is understandable and correct:

- Nano as a common denominator is too loose for targeted funding.
- The OECD and international funding organisations, like the EU, are moving from tool orientation to problem orientation.
- Nano has now become one scale of operations in different disciplines that have less and less in common.

This means that the next instruments implemented by Tekes and the Academy should be something other than nano programmes. Thus, the emphasis on maintaining nano as a subject is being transferred to networking organisations. In the following we present proposals and ideas that are based on the evaluation materials, interviews and the evaluation workshop held in June, 2010.

### Recommendations for Tekes, the Academy and the MoE

Nanotechnology and nanoscience seem to be in a phase where further programme activities may prove ineffective. For SMEs, nano-OSKE, once properly introduced, provides reasonable networking services. For big companies, SHOKs provide possibilities for similar activities, once the nano aspect is driven into them. On the other hand, typical Academy applicants have already existing scientific collaboration networks and forced networking activities are seldom useful. Also the nanotechnology per se has come to a position where further branding actions would be rather futile (see 7.1).

For individual start-up companies, various start-up tools and funding opportunities are very important. One way to respond to the difficulty of starting companies would be to strengthen the NIY-funding offered by Tekes by extending the duration and volumes. NIY is funding for young, innovative growth companies awarded by TEKES. It consists three phases: business planning (preliminary), prerequisite growth (phase 1) and rapid growth (phase 2). They include a growing amount of funding for fewer companies. The programme is directed at companies younger than five years in the beginning of the preliminary phase, while the funding is ended when they reach the age of eight, at the latest. Other basic criteria are that the participants must be small and SMEs during the funding; companies must have a plausible business idea with sufficiently large business potential and they must be growth-oriented, aiming mainly at the international market. Key personnel must be committed and, if necessary, willing to extend the ownership while at least 15% of all costs are allocated to R&D. The companies are evaluated between and during the phases and decisions are made for funding in the next phase.

At this point, existing research results from the projects in the programmes should be utilised as much as possible. Perhaps the most important aspect would be to have funding for researchers and companies to facilitate IPR protection of their achieved promising results. As this is part of commercialisation services, Tekes might be a suitable stakeholder here.

For basic research, many research results automatically serve as merits for continuation funding. Although the nano programmes do end, funding of nanosciences using other instruments should not end categorically.

In the evaluation it became quite evident that nano-related research work in Finland is fragmented in rather small groups. The present funding systems, where funding is dispersed into small annual sums, support the tendency of small groups. It is generally thought that enlarging research group size is beneficial due to increased communication, shared resources, shared

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50 ibid.

networks and smaller amount of possible overlaps. Therefore, it might be beneficial to change the funding system so that it would encourage larger groups and gradually create units with critical mass in global comparison. Changing the existing funding structures would be estimated to take some 3–5 years.

International funding sources for research are more and more important, and national funding agencies should perhaps act more as matchmaking organisations which would help Finnish researchers target their funding applications.

As reported earlier, the MoE nanoscience funding has had good objectives but the funding model has been somewhat inconsistent with the existing tools and methods. As a part of making the Ministry's university guidance more general, the MoE is now shutting down the funding system as such.

It should be noted, however, that if experimental nanoscience is desired to be a part of the Finnish research portfolio then, irrespective of the funding organisation, equipment funding should be reorganised from ownership to usage and services:

1. Funding mechanisms must be more coordinated and form a continuous flow of funding. Since the equipment is expensive, this will require making strategic choices of which areas to fund. Most likely, a small-scale infrastructure roadmap exercise focusing only on nanoscience and technology would be beneficial.
2. As a part of funding mechanism, follow-up mechanisms must be improved, and follow-up results must have a clear impact on future funding decisions.
3. Funding must promote cooperation. Instead of monolithic allocation to physical equipment, there should be funding for the use of equipment located possibly elsewhere. Use here means not only the usage fees but travel expenses and living costs. This would also promote internationalisation, as researchers could possibly use foreign equipment more efficiently.
4. Funding must be based on credible usage plans. There must be plans for the use, cooperation, anticipated results, and impacts. The plans must be monitored, and should there exist gaps, explanations should be required.
5. There must be guarantees that the equipment is used throughout its life cycle. On one hand, there should be a documentation of the use and the results. On the other, there should be at least a partial amortisation mechanism for the equipment so that the expenses of the equipment match reality. Furthermore, there should be mechanisms that secure the ability to use the equipment also in the event that a key person leaves the research group.
6. There should be sufficient personnel to take care of the equipment. Ideally, there should also be a process support group whose task would be to compile experiences and tacit knowledge and help researchers operate the equipment.

Most of the requirements above fit well with a model where a dedicated centre owns and operates the equipment. Research group commitment must, however, be achieved. Therefore, departments and universities should be stakeholders in these centres. In fact, the Ministry of Culture and Education has already undertaken one funding exercise in the field of bioscience equipment, where these guidelines are more or less followed[51].

The role of polytechnics in the Finnish innovation system has been somewhat challenging ever since their establishment. Moreover, there were very few polytechnics in the programmes studied here. In earlier evaluations[52], it was concluded that one suitable role for polytechnics would be participation in applied research projects as a system integrator and in expertise in projects requiring multidisciplinary practical approaches. Nanotechnology, however, seems to be a field where such expertise is not yet re-

[51] Biocenter Finland is currently a collaboration network of six biocentres, which are located at six universities. Biocenter Finland coordinates and develops basic education and research training and aims at establishing effective connections with clinical investigators at university hospitals, biotech businesses, and polytechnics. One of the main tasks of Biocenter Finland is to pay particular attention to emerging technologies in order to avoid any undue delay in their transfer to Finland. Since its foundation in 2006, Biocenter Finland has with the support of the MinEdu coordinated the restructuring of the nationally important technology platforms and services in a number of areas.

[52] Raivio et al. (2006)

quired. The situation may change in the future, but at present, the role of polytechnics in nanotechnology must be determined case by case.

The collaboration of the FinNano programmes and MoE funding, especially in the preparation and application phase of the programmes, proved to be very valuable in terms of preventing overlapping, redirecting applications and, above all, in enhancing funding coherence. The problem with the cooperation at the moment is that it is based on voluntary work. It is therefore recommended that this kind of cooperation be formalised in a suitable way. There should be different procedures for identifying cooperation needs and implementing cooperation.

### Recommendations for collaboration organisations

Whereas funding organisations are gradually eliminating nano as the common denominator, the role of the collaboration organisations is becoming emphasised. Nano-OSKE has listed over 400 companies in its network and acts as a strong regional network organisation. To this end, it was surprising to discover that the knowledge of OSKE among the companies participating in the programmes in this evaluation was limited. More information is definitively needed. In the interviews the redundancies and overlappings in the working models of regional nano-OSKE centres were pointed out. It therefore recommended that the regional nano-OSKE centres coordinate their work more, e.g., by specialising in different aspects of OSKE work.

Another clear need for OSKEs is better contact with both companies and research groups. In this way, the strong and acknowledged networking capabilities of OSKE activity can be further utilised. Nano-OSKE could possibly have a role in the open innovation system as an organisation that could enable research result transfer to companies. Thus, nano-OSKE would participate effectively in maintaining the nano brand, and the nanotechnology companies currently operating would not be ignored.

On the other hand, nano-OSKE could strengthen the coordination of nano research equipment usage, which the Mikkeli centre already does. In this field, there is much to improve; according to an example from the real world some services can be obtained faster from China than from Finland.

In the light of the evaluation, the connections of nano field to SHOKs (Strategic Centres for Science, Technology and Innovation) are, in practice, nonexistent. This is understandable considering that the SHOKs are just organisers. However, given that one of the main problems in the Finnish nanotechnology and research field is that companies do not take nanotechnology into full use, SHOKs should have a far more central role in adopting and promoting nanotechnology. One possible way to implement this would be to aim at organising a body partly-funded by the European Institute of Innovation and Technology (EIT) and the Knowledge and Innovation Community (KIC) consisting of between 2–3 of the most relevant SHOKs, Tekes and the Academy to promote nano-related research and development.

In the assessment of the national innovation system, the main points relevant to this evaluation, which the evaluators would like to put forward, are[53]

1. Strategy systemic view is not fully integrated
2. Innovation system is exceptionally domestic
3. Regional dimension is strong but ignored
4. Insufficient attention to high-growth entrepreneurial firms.

This evaluation has already pointed out points 3 (Nano-OSKE) and 4. For the nanosciences and technology, internationalisation is hardly a problem, as most researchers are strongly networked and a large number of nano companies aim to engage in operations abroad. Cooperation between the programmes has been an excellent example of activity integration. In this sense, the findings of the assessment do not seem to require any special efforts.

### New initiatives

In Finland, there are many internationally recognised nanohealth research groups, and this might be an appropriate time to promote these research capabilities by founding a nanohealth centre that would focus on research innovation and development of nanoparticle-related health issues. Potential stakeholders for the centre would be the Finnish Institute of Occupational Health (TTL), the National Institute for

[53] See www.evaluation.fi

Health and Welfare (THL), universities and companies. Other possible themes would be water treatment or environmental nanoparticle monitoring.

A couple of years ago Nokia, together with Tekes and Technopolis, set up the Nokia Technopolis Innovation Mill, whose purpose is to transfer innovations that Nokia does not require into SMEs and other companies across Finland who may be able to turn them into world-class products and services. A similar approach would be suitable for nanotechnology; Nano-OSKE could implement a nano innovation mill, and Tekes would fund the operation. In addition to innovation banking, a special mentoring bank would serve young companies.

Nanotech Finland – the umbrella network of Tekes, SA, the MoE and OSKE, has a significant promotive role. Through Nanotech Finland, Finnish nanotechnology can present itself as a unified entity. Nanotech Finland would be a suitable party to maintain the international visibility of Finnish nanoscience. Suitable forms of visibility could be, e.g., aiming at innovation alliances with China and Russia. The funding could come, at least in part, from Tekes.

# 8
# Summary and conclusions

The evaluation at hand has evaluated coordinated nanoscience and technology funding from the past 15 years. The targets have been the Nanotechnology programme (1997–1999), Tekes' FinNano programme (2005–2010), the Academy of Finland's FinNano programme (2006–2010), the Ministry of Education's nanoscience funding (2007–2009) and the cooperation between the three latter.

In the light of the analysis, all the programmes have succeeded well. The early Nanotechnology programme was a nano catch-up programme that increased Finnish knowledge about nanoscience and technology by gathering different disciplines under a common technological denominator. The Tekes and Academy FinNano programmes have boosted Finnish nano research and business, and the MoE's nanoscience funding has provided partial funding for research infrastructures. Cooperation between the programmes mainly took place behind the scenes, but it was essential to prevent overlaps and to increase the coherence of funding.

As a slight downside of each programme it may be mentioned that the Nanotechnology programme was a catch-up type programme. Tekes's FinNano programme did have large company coverage, but it was mainly through joint funding of research projects. The Academy's FinNano programme seems to have suffered slightly from the fragmented nature of funding, and the funding mechanism used in MoE nanoscience funding was somewhat incompatible with the intended, rather precise targeting of the funding.

In the analysis, several development points were identified that cannot be affected by programmes. Furthermore, nano as the common denominator is losing its significance. Therefore, the next developmental steps should be implemented by other means, such as technology transfer, encouragement towards entrepreneurship, increased seed funding and basic research funding focusing on problems rather than disciplines, to mention a few.

During the evaluation it has become evident, that Finland cannot have it all. Finnish resources are small, and strategic choices are needed. Fragmentation of research funding leads to ever diminishing funding portions with diminishing impact. Uncoordinated research equipment funding leads to inefficient equipment procurement and usage, and current models discourage cooperation. Companies and networks suffer from the uncertainty related to late or lacking choices. Clear strategic choices must be carried out and they have to be coherent and predictable.

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# Annex 1. Interviewees and workshop participants

**Interviewees**

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October 2010

ISSN 1797-7347
ISBN 978-952-457-510-2

Ministry of Education and Culture

Suomen Akatemia
Finlands Akademi • Academy of Finland

Tekes