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Electrically Conducting Polymers in Sweden

- Networks and Entrepreneurs in the Creation of a New Area

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SUMMARY

The discovery of electrical conductivity in polymers was awarded the Nobel Prize in chemistry in year 2000. The three winners (A. Heeger, A. MacDiarmid and H. Shirakawa) established that polymer plastics can be made to conduct electricity if alternating single and double bonds link their carbon atoms, and electrons are either removed through oxidation or introduced through reduction. The extra electrons or corresponding “holes” can then move along the “doped” molecule, making the conjugated polymer conduct electricity almost as well as a metal. (*Nature*, October 12, 2000) Through interdisciplinary research chemists and physicists have taken the field further during the 1980s and 1990s. They have discovered that organic polymers can be induced to light up. Layers of these conducting polymers could help to create a number of interesting applications. Electronically Conducting Polymers (ECP) is a part of the new materials sector. In this paper the specific ECP-area is considered to be a science-based technology.

Swedish research teams entered the field of ECP in the beginning of the 1980s. This report mainly follows the activities of these research groups, their financing, knowledge production, links to other actors in universities and companies and other networks. The main interest of the paper is to investigate networks, collaborations and tendencies to interdisciplinarity in a field characterised as a science-based technology.

Analysis of research networks and links

Nature, evolution and transfer of knowledge

There is no doubt that the ECP area in Sweden has developed through spontaneous networking activities, which to a large extent have been and are dependent on personal relations and personal affinities. Personal friendship is one frequent explanation for collaborations in the interviews. Of importance for the area of ECP-research are three different groups from three different universities: The IFM-group in Linkoping, the CTH-group in Gothenburg and the KTH-group in Stockholm.

From the very beginning Linkoping (the IFM group) has been the centre of research in the ECP area. Others have tried to enter it, but for different reasons, mainly due to scientific choices and/or organisational weakness, they have had to remain in the periphery. Linkoping had several advantages compared to others. At the time for the first discoveries, when the scientists entered the area, Linkoping was a newly established university, with a lot of young professors. The university chose a new form of organisation with large, multidisciplinary departments, which were all located in the same building. This ”localness” has generated a close relationship between professors of different specialities and between post graduate students as well. Other universities (the big five) all have their respective disciplines in separate buildings.

The IFM group had one disadvantage – lack of competence and experimental capacity in chemistry. To handle this they concentrated on a substance they could produce by themselves, polypyrole. This had two important consequences. First, they developed a specific competence which made them an interesting partner in collaborative work with other researchers/laboratories. This gave them an extensive network of international relations during the 1980s. They also recruited a researcher from the U.S. Second, they learned about a different trajectory than the route mostly taken during that time, polyacetylene, and that gave them an advantage later on when the major trajectory seemed to be a dead-end.

In 1985 IFM also started a collaboration with chemists in the CTH group, leaving the KTH group aside. The co-operation with the CTH group was expanded during the partnership within a Nordic network, mainly with Finnish companies and researchers. This gave the Swedes new and better materials, cleaner and larger amounts, which also made it possible to conduct comparative experiments on exactly the same material.

Exactly why the group at KTH did not manage to get themselves included in the IFM–CTH network is open to different interpretations. One is that the competition during the first period led to a situation where the groups more or less fought over funding and ideas. The KTH trajectory was polyacetylene whereas the IFM followed another path, the polypyrole. This could have made it hard for them to co-operate as they had to fight when it came to funding. Another fact to take into consideration is that the STU agency probably found it easier to work with people from the physics departments than with organic chemistry. The polymer technologist in Sweden also had an in-depth relation to their industrial partners and none of them was interested in the emerging areas of electrically conducting polymers. A third explanation is that the STU agency was a weak actor in the field. The programme officers tended to rely on their relations towards their former supervisors and were weak in building up new relations in areas with a high level of insecurity. A fourth answer as to why the STU was slow in their actions, although people at the Ericsson company suggested fast moves and flexibility, is that the agency found it difficult to act in areas where there were no explicit firm initiatives.

The first networking activities were conducted by the IVA (with support from STU), and this certainly pushed the area forward. Really important networking, in the form of forcing groups of researchers to co-ordinate their efforts, was not done before the NIF took the initiative in 1986. While this did not last for long, it certainly started collaborations between Swedish and Finnish researchers that has had a long-term effect on the competencies and the capabilities in Sweden.

ECP and interdisciplinarity

Interdisciplinarity is closely connected to the organisation of research. Lack of synthesis chemistry was a drawback that the IFM group overcame through their co-operation with CTH and the Nordic network. Those more permanent relations had a stronger effect and gave momentum to the interdisciplinarity of the research in Sweden. The younger researchers who entered the area after 1985 have generally had less disciplinary boundary-making in their education, especially in Linkoping, and we have been told that they normally have contacts with people from other disciplines. For example the physicists in Linkoping try to send their post docs to chemistry departments in the U.S.

As long as the researchers do more basic science, there is not an instant need of interdisciplinary contacts. The different groups can specialise in their specific experimental techniques. From this fact interdisciplinarity can be interpreted as a consequence of the application-driven routes in the area of research. The nearer an application, the more you will need competencies form both physics and chemistry.

The type of interdisciplinary work that is often performed in laboratories in the U.S. is very seldom done in Swedish labs. In the conceptual scheme proposed by Schmoch, and referred to in the full report, we would conclude that research in Sweden has been pluri- and crossdisciplinary in its character. The groups involved conduct mutual work on the interpretation of experiments and in the planning of research. At the same time there seems to be an elaborate division of labour between the groups and the disciplines. Even within one discipline we have found that there is an intricate division of labour. While some researchers develop their own specialities through competence in, and by obtaining, complex instruments, others develop their niche as generalist researchers who pick up results from others and join them together, often with applications in mind. Following Law (1976) we use the concept ”subject matter speciality” to depict the latter and ”technique/methods based speciality” for the former. One has to take this dimension into consideration to perform a complete analysis of the interdisciplinary relations in certain fields of research.

Incentive structures

There has been no national actor capable of co-ordinating the resources for research in Sweden.

A spontaneous network has been built up based on personal relations.

The lack of chemical competence at the IFM has been a driving force for co-operation with other groups, nationally and internationally. In the beginning the physicists could do without direct collaboration with chemists, but after a while they had to develop competence on their own and competence through others.

Lack of instruments at the departments of chemistry forced chemists to get in contact with physicists. The physicists provided them with results from different kinds of measurements.

Commercialisation

The lack of industrial interest can be explained with reference to the character of the chemistry and plastics industry in Sweden. The sector is small and more concerned with the processing of bulk materials. The firms have no interest in products outside their specific niche. Applications of the scientific findings have not been likely in the short-term, and because of that the industry’s policy is generally that the state should support basic and strategic science. The division of labour is strict in Sweden.

In 1997 people from the IFM-group finally seems to have taken a major step towards commercialisation of research. With finance from Norway, a research centre is to be set up at the science park of Mjardevi, nearby Linkoping University. A total of fifteen researchers are to develop some of the routes of research developed in the IFM-group.[1]

Policy issues

With the high concentration on the university sector follows a wider range of duties than in most other countries. The sectorial agency for support of engineering technologies, NUTEK, has developed a variety of ways for organising the support to the university-based research so that it will be performed in ways that go along with industrial relevance and the strategic aims of the governments long-term economic policy. This has affected considerably research on materials science in Sweden.[2]

NUTEK programmes in materials technology have always been directed towards areas of interest to Swedish firms. That is, technology for components and materials for the engineering industries and the construction sector. Typically, most of the programmes in the polymer area have been devoted to polymer processing and properties.

The overall research climate for efforts in materials science and technology (like conjugated polymers) has been positive during the whole period we are investigating.

Although the agency for technical development, STU/NUTEK, had a policy which focused on networking as a major pillar of their programme, they did not manage to connect the different research groups in Sweden. Instead it seems as if the STU was detrimental to the development of the area. Most of the support went to polymers as insulators, although the actual programmes started as ECP programmes. We have found that the explanations for this are twofold: 1) A mechanistic, slow and anxious implementation of policy at the agency. Even though there were no private firms interested in ECP, firms with other interests were invited to join the programme steering committee. 2) Powerful academic actors in the polymer technology area took leading roles in the committee.

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[1] Source Interviews and Web sites.

[2] Materialteknik, underlag och förslag till insatser inom ett nationellt program. STUs informationsenhet. (August 1989). In this programme interdisciplinarity, lon-term financing, co-operation and networking (national networks for strengtheing of R&D-groups and access to international collaboration. In the programme ECP was mentioned as a possibility in the future, but in the proposed efforts ECP did not appear as one strategically interesting area.

INTRODUCTION

Within the network approach, organizations are seen as interrelated, although not necessarily in a formal structure. A network can be defined as a form of inter-organizational cooperation, with relative permanence and with relatively stable but not fixed boundaries. A network gives an organization access to resources, information and partners by entering into more or less formalized cooperation with other organizations. A network is, because of its loose and informal character, a more flexible organizational form than vertical integration (a corporate hierarchy), but this also means that its reproduction is dependent on a shared understanding of the role and content of the network. Thus, shared cognitive norms of the cooperation, and professional ties between the participants are among the preconditions for a network (Powell & Smith-Doerr 1994).

We have applied a general conception of networks as more or less permanent interactions between a variety of actors (firms, public sector researchers, and government sponsors) in the field of research under study. A large part of the analysis is about social networks (Mizruhi), but organizational networks are of interest as well. A dynamic approach, like the one proposed by Debackere et al (1994), seem to be appropriate, especially for the ECP study.

Interdisciplinarity is hard to define as well. We have followed the conceptual scheme proposed by Schmoch et al (1996). Thereby we can distinguish between different levels of interdisciplinarity: *multidisciplinarity*, where research is conducted in the forms of autonomous and internally structured disciplines working on a common theme, i.e. a weak form of co-operation, *pluridisciplinarity*, which ”means co-operation without co-ordination of different disciplines in one project” (ibid.); *crossdisciplinarity*, representing the integration of disciplines ”where one discipline dominates” (ibid.) and where disciplinary structures are transcended by the evolving formulation of new terminology or methodology; finally, *transdiciplinarity*, which describes ”the melting of disciplines which are studying the same disciplines” (ibid.). The difference between pluri- and crossdisciplinarity is perhaps the weakest in this scheme, but we presuppose that in the former there is no transfer of tacit knowledge, which, to some extent, takes place in the latter. A constant transfer of tacit knowledge characterizes the mutual co-operation that takes place in transdisciplinary collaboration.

THE SWEDISH RESEARCH AND INNOVATION SYSTEM

Like other small industrialized countries, Sweden is highly dependent on international trade to maintain its productivity and living standards. In 1994 exports were equivalent to more than one third of Gross Domestic Product (GDP). About 80 per cent of total exports consist of industrial products.

The Swedish economy depends strongly on a limited number of very large international companies. The dominant role of a few large companies is especially apparent in manufacturing. In 1990 the ten largest Swedish industrial companies employed nearly 600,000 people. Of these, 240,000 worked in Sweden. The concentration of industrial output within a few very large companies is a major contributing factor to the relatively high level of research and development (R&D) spending in Sweden. Swedish multinationals are among the most R&D-intensive in the world, and over the years most of this R&D work has taken place in Sweden. However, in the 1980s there was a contraction in the knowledge- and research-intensive industry. During the second half of the 1980s, there was an increase in both Swedish direct investments abroad and in the percentage of R&D that major corporations performed in units outside Sweden. Studies show that despite the fact that Sweden has a high investment in R&D, the Swedish economy ”produces only a below average percentage of R&D intensive products relative to total manufacturing, compared to the average for the OECD countries”.[3]

In Sweden as in many other countries (Germany, Japan), industry itself is the major source of funds for performance of R&D. There is a marked difference compared to the US, the UK and France in this respect. Government defense accounts for most of this variance. Government support for R&D in the business sector almost totally (80 %) concerns technology procurement for defense purposes. For the performance of R&D in academic institutions, the government in Sweden is the major provider of funds. The actual figure is between 85 to 90 percent and that is, or has been, at least 10 to 20 percent higher than in other countries. This concentration on the university sector as regards public support of research is the result of a conscious policy in Sweden. The aim is to maintain a link between research and education and to avoid splitting up scarce research resources.

[3] McKelvey & Edquist (1997), p. 2

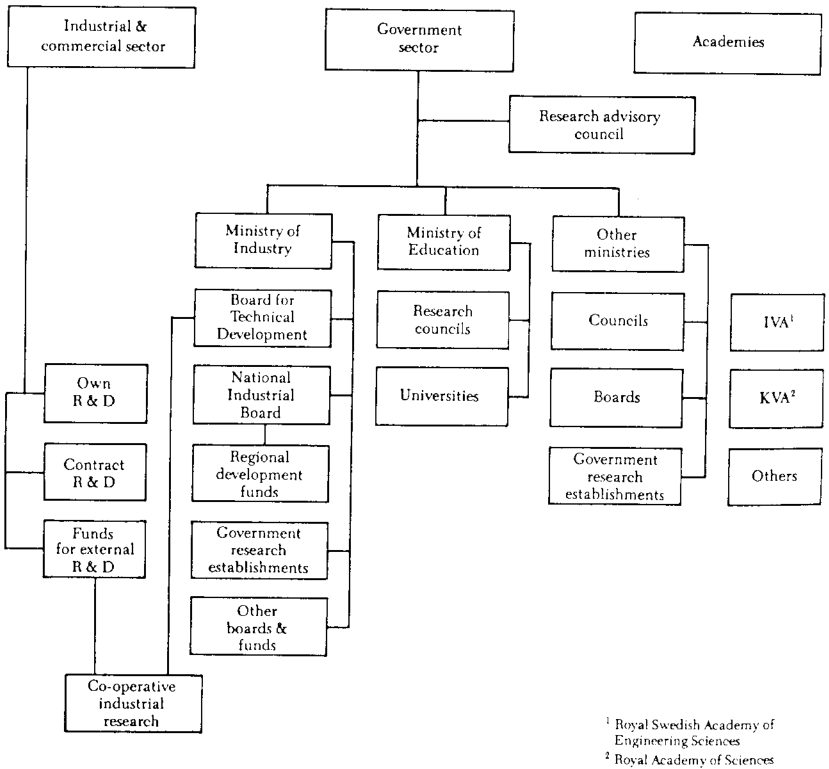

Fig 1. *Organization of Research in Sweden* (Source Royal Acad. of Engineering Sciences)

Research is an important part of the higher education system. Practically all higher education research is integrated with and founded on close, local co-operation with the undergraduate and post-graduate study programs of the educational establishment concerned. This applies both to basic research at higher education institutions and to what is known as sectorial (i.e. mission-oriented and externally funded) research. The universities and the institutions with post-graduate education have permanent resources for research.

In Sweden, with the exception the University of Agricultural Sciences which lies within the jurisdiction of the Ministry of Agriculture, almost all higher education institutions are under the direction of the Ministry of Education and Science i.e., they are run by and are under the control of the central government. The employees at these universities and university colleges are national civil servants. Seven of the central government-operated higher education institutions are universities. These are the Universities of Uppsala, Lund, Gothenburg, Stockholm, Umea, Linkoping, and the University of Agricultural Sciences. There are three more which are specialized institutions of higher education and research – the Karolinska Institute (medicine), the Royal Institute of Technology, and Lulea University College and Institute of Technology.

Research Policy. The main responsibility for funding basic research and postgraduate education devolves on and has been assumed by the state. Research is one of the very few sectors funded by the government where funding has increased in recent years. The proportion of external, non-state funding in higher education is also increasing.

Universities and university colleges account for nearly 90 percent of all publicly funded research if research for defense purposes is excluded. This means that control of research within the higher education sector is the major influence on the overall direction of research in the country at large. By tradition, basic research and education of graduate students, as well as technology transfer, are carried out in the universities. In this sense Sweden is different from most other industrialized countries, where the universities take care of the education of graduate students and basic research, while technological research and technology transfer are to a much greater extent performed through research institutes, e.g. the Fraunhofer institutes in Germany. The closest parallels are with Australia and Canada.

Government support to the universities for specific research awards flows through three Research Councils. The Engineering Sciences Council (TFR), the Medical Research Council (MFR), the Natural Science Research Council (NFR). The mechanisms are both general support and project and program support. The research councils consist largely of scientists appointed by academic electoral assemblies. However, a small number of council members represent societal interest and are appointed to the board by the government.

Considerable research funding is allocated in Sweden by sectorial bodies reporting to other ministries. Their task is to ensure that the research and development needs of a certain sector of society, or a certain priority field of policy, are provided for. This is true not least for research that has a direct focus on business enterprise. A great deal of public support for technical research and industrial development, building and energy research is distributed by the National Board for Industrial and Technical Development (NUTEK, the former STU).

Various industrial research institutes maintain R & D co-operation with industrial organizations. The main task is to engage in research of common interest to a group of companies or industries. In addition, and to a varying extent, they accept commissions from individual firms. Competitively neutral basic and applied research is carried out, and commissioned and testing activities are undertaken in this connection. There are about thirty industrial research institutes, financed jointly by the state and the enterprise sector on a foundation basis. Their turnover for 1993/94 came to about SEK 850 million.[4]

The government performs relatively little of its own research, although some mission agencies maintain their own laboratories (e.g. working life studies). There are no national laboratories, and the national universities are the main performers of research and house large laboratories.

R&D in Sweden focuses heavily on certain key industries. Between them, the five biggest R&D sectors account for more than 80 percent of all research and development in industry. Pharmaceuticals are the most R&D intensive industry, with expenditure equaling nearly 42 per cent of value added. Twenty-seven per cent of current (1991) R&D expenditure can be associated with telecommunications products, 20 per cent with the transport technology product group, 13 per cent with pharmaceuticals, and 10 per cent with machinery other than computer hardware. Research accounted for 13 per cent of corporate R&D. Nearly half of all R&D activities are aimed at improving existing products or processes. Just over half focuses on new product development, processes or systems for a company or market and on knowledge production in general.

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[4] SOU 1996:70 Samverkan mellan hogskolan och näringslivet NYFOR-kommittén p. 41. One third of the financing comes from the government.

The non-socialist government decision to phase out the wage-earners funds and use them for so-called New Research Foundations produced a substantial transfer of funds to support Swedish research and postgraduate studies. Seven foundations have been established for the purpose of funding research and related activities in different areas. The Foundations have led to a strengthening of many fields of research, primarily in environment, health care, problem-oriented natural science and engineering areas, (i.e. biosciences), information technology, medicine and ”basic technologies” (e.g. forestry). The major part of the new funds is used for project support to universities (approximately SEK 1.5 billion per year).

Co-operative work with the EU has become increasingly significant; especially since Sweden became a member and so obtained better opportunities to influence the scope and focus of R&D programs. Approx. SEK 500 million a year will be allocated to universities & institutes of technology in Sweden.

The pluralism of the Swedish system for research funding is apparent. In engineering and technology research there are at least three large agencies: TFR, NFR and NUTEK, together with the so-called Strategic Foundation (SSF). While TFR and NFR are oriented towards basic research,[5] NUTEK has a responsibility for applied research. The activities of SSF will probably straddle the two. As a rough approximation, these bodies allocate SEK 1,5 billion, whereas the faculty appropriation is SEK 1 billion. The Research Policy Act of 1996 reallocated SEK 300 million from NUTEK since the SSF is supposed to fund strategic engineering research.

ECP CASE-STUDY SWEDEN

The focus of this case study is on the organization of knowledge production for a specific technology, which presumably, from an operational definition, is science-based. Because of some fundamental distinctions that will be used later on in the report, we start with a short description of the particular area of research. The next introductory section is devoted to the academic actors, the Technical Institutes in Linkoping, Stockholm and Gothenburg. Also the state agencies involved in the area are described and the boundaries of the sector are discussed in this introduction.

Outside of the academic scene there has not been much of interest into ECP research in Sweden. Because of this the report has concentrated on the evolution of academic research and the networking activities performed by researchers and supported, or destroyed, by state agency officials. The story itself is surprising and perhaps of general interest from a policy perspective.

The concentration on academic actors and their relationships has made it possible to study, in more detail, the actual interdisciplinarity and the organizational problems that is related to this

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[5] NFR allocates funds mainly to natural sciences, but some areas (physics) have strong connections to engineering and technology research. Many of the researchers funded by TFR also receive money from NFR.

question. Networking and interdisciplinary research is deeply connected to each other, but always within the restrictions of the main lines, or paradigmatic routes (trajectories), of the scientific field of research. How this can be interpreted is hinted on in the report.

INTRODUCTION: THE AREA, THE ACTORS AND THE SECTOR IN SWEDEN

Conjugated and Conducting Polymers

The interest in this area of polymer research started in 1977 when Shirakawa, MacDiarmid & Heeger discovered that polyacetylene had a fairly high electrical conductivity after chemical doping. Since then, research in this area has been intensive. The large family of conjugated polymers is materials capable of being doped, through chemical oxidation or reduction, to states of high electricity. Three other types of doping methods have been developed over time:

- electrochemical,
- photo-doping and
- doping by charge injection at a metal-insulator-semiconductor.

Following the analysis of Heeger (1993) these methods can be interpreted as four different trajectories within the ECP-paradigm. Each of these trajectories utilizes doping and undoping for specific types of applications, e.g. lightweight batteries, lightweight electrical conductors, energy conversion devices, electro-optical devices and different products in the area of electronics (field effect transistors).

During the 1980s many of the chemists and physicists in the USA, Japan and Europe concentrated their efforts on raising conductivity and on solving the problems with stability and processability, principally for polyacetylene. Polyacetylene was the polymer for which the researchers managed to reach the highest conductivity, in fact almost as high as copper.

To produce polyacetylene you need access to syntheses chemistry. As a consequence several physicists started to produce and experiment with the conductivity of other polymers. Because of problems concerning the stability of the polymers, conductivity decreases quickly in air or normal temperatures. When the researchers did not find a solution to this problem in polyacetylene, their interest turned to other conjugated polymers, mostly polythiophenes. A marked change towards other substances occurred during the period 1984 to 1986. Stability increased, but the ability to process the material was not solved.

Because of the problems described above the focus of the research turned *from* the conducting properties at the doped state *to* the undoped. This happened in the end of the 1980s. Undoped polymers are semiconductors and within this line of research, the optical properties in particular have attracted a wide interest. New ranges of possible devices have arisen, for example light-emitting diodes, photo-diodes, solar cells and lasers.

Our conceptual interpretation of the above is that there are many different possible fields of research in the larger area of conducting and semi-conducting polymers. As a scientific field, it would probably be incorrect to define it in terms of a certain paradigm. Instead this area seems to be in a pre-paradigmatic phase, with a number of trajectories that are used as experimental routes for the technological researchers. Achieving the highest possible (stable) conductivity for a polymer through a doping process has been one of these trajectories which has consumed a lot of research effort from different groups all over the world. Other trajectories have more or less accepted the semiconducting properties and have tried to find applications for this. In the science base of the area there are several lines of research that are more or less directed towards a scientific understanding of the materials and their properties. During the 1980s, a lot of highly esteemed researchers (Nobel Prize winners) came into the area.

The ECP Sector and Related Research Agencies in Sweden

What sector is this? In the preparatory paper it was stated that ECP is part of ”the chemistry sector”, but also has ”a link to the electronics sector”. From the Swedish point of view we are not sure that this description is completely correct. The problem is that ECP has been evolving in several directions over time and the definitions that were common during the 1980s are no longer accurate. It seems as if it is correct to call ECP a part of the new materials sector, with many possible directions. At least this is how it has been handled in Sweden. That might be due to the low public research activity in the chemistry sector. An explanation for this can be found from the following description of the relevant part of the industrial structure in Sweden.

In the area of ”polymer materials” related to polymer physics and polymer chemistry, only a few companies have been established during the period since the late 1970s when the first scientific discoveries were made. Mainly, the industries in Sweden are users/converters of polymers rather than producers. This poses problems for the research groups involved in this area, since there is no direct interest in fundamental polymer science and technology per se. Two companies dominate the Swedish production of plastic primary products, Neste (Finland) who produces polyethene and Norsk Hydro (Norway) with a production of PVC. Some of the larger companies among the processing industries have conducted polymer-related research on their own, e.g. ABB Polymer AB (the former ASEA) and Nobel Plastics AB. In the latter R&D costs are about 3 per cent of sales output, but in the primary industries it is very low, less than 0.5 percent.

There has been one industrial research institute for the plastics and rubber industry, but a small one and concentrated solely on developmental work related to the larger companies in rubber and composites. Since 1993 it has merged with another institute directed towards fibers and composites. The institute conducts contract research on a project basis.

As mentioned earlier R&D in Swedish manufacturing firms is dominated by development as distinguished from research. The responsibility for research has to a large extent lain on the state and the public sector. At the same time the number of research institutes (privately or/and publicly financed) is very low and of little importance in the national system of innovation. As a consequence the university system has the obligation to perform all types of research – basic, strategic and applied.

With the high concentration on the university sector follows a wider range of duties than in most other countries. The sectorial agency for support of engineering technologies, NUTEK, has developed a variety of ways for organizing the support to the university-based research so that it will be performed in ways that go along with industrial relevance and the strategic aims of the governments long-term economic policy. This has affected considerably research on materials science in Sweden.[6] In 1989 thirteen governmental authorities presented an outline for a national materials technology program and, at the same time, NUTEK and the NFR launched a program for materials science consortia's. A specific budget in the Research Bill was set up and eleven consortia's started in the beginning of the 1990s. These consortia's were part of a bold strategic and venture into what was regarded as generic technologies of industrial relevance for future industries in Sweden. One conclusion of this is that the overall research climate for efforts in materials science and technology has been positive during the whole period we are investigating.

At the same time it should be underlined that NUTEK programs in materials technology have always been directed towards areas of interest to Swedish firms. That is, technology for components and materials for the engineering industries and the construction sector. Typically, most of the programs in the polymer area have been devoted to polymer processing and properties. In the strategic venture for materials science that started in 1990, these aspects of polymer technology also came into focus. Of the eleven consortia's established one is a Gothenburg-centered program on Interfacial Interactions in Polymeric Materials. Here the interest is mainly on the properties of polymeric blends and composites.

It should be noted that the rationale of the consortia's is to include industry representatives in the program committees and to underline the need for industrial relevance. With this emphasis on relevance from the point of view of the actual industry it is obvious that more advanced applications of knowledge in polymer technologies have no industrial partners in Sweden. That has been the case for the whole period and the exceptions are very rare. An illustration of this can be given through the history of the STU/NUTEK activities in the ECP-area since the beginnings of the 1980s. From the story we will also understand why the proposal that was sent in from the ECP groups in Sweden, suggesting a materials consortium, was turned down.

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[6] Materialteknik, underlag och förslag till insatser inom ett nationellt program. STUs informationsenhet. (August 1989). In this programme interdisciplinarity, lon-term financing, co-operation and networking (national networks for strengtheing of R&D-groups and access to international collaboration. In the programme ECP was mentioned as a possibility in the future, but in the proposed efforts ECP did not appear as one strategically interesting area.

Academic actors in the ECP-area in Sweden

All figures in the following presentation of actors refers to the situation in 1997.

Linkoping University (LiU)

Linkoping's university is divided into three faculties, the Institute of Technology, Health Sciences (Medicine) and Arts & Science, and employs 2 600 people. In addition there are 1 100 doctoral students and about 15 400 students in Linkoping (and Norrkoping) together. The Institute of Technology was founded in 1969 and consists of eight large departments. Within each department there are several divisions. The campus consists of few quite big buildings, so researchers from different departments share the same premises. Research into ECP is performed at the Department of Physics and Measurement Technology (IFM).

Department of Physics and Measurement Technology (IFM): This department consists of twelve divisions (or laboratories as they are called below). About 350 people are employed at IFM and around 130 of them are graduate students. Several of the divisions have occasionally done research that is connected to the ECP-area. However, there are two laboratories that are the main actors in this research field, Applied Physics (AP-group) and Surface Physics and Chemistry (SPC-group).

Applied Physics (AP) started in 1978 when Ingemar Lundstrom was appointed professor of the laboratory. Today there are 40 - 50 people working at Applied Physics. At present a small group of six are doing research on conjugated polymers. The number has fluctuated; two years ago the ”The Conjugated Polymer group” consisted of about fifteen researchers.

The *Surface Physics and Chemistry* laboratory (SPC) started in 1983 when William R Salaneck was awarded the chair. Since then it has consisted of about 10–14 researchers.

Since the mid 1980s a small group (three or four) at *Theoretical Physics*, mostly PhD-students, have been doing some calculations concerning conducting polymers. The same is true for the laboratories for *Electronic Devices* and *Chemical Physics*.

Royal Institute of Technology (KTH)

The Royal Institute of Technology is the oldest and largest Institute of Technology in Sweden. KTH was founded in 1827 and has one third of Sweden's capacity of engineering studies and technical research at post-secondary level. At the KTH there are about 2 500 people employed, 1 000 graduate students and around 10 000 undergraduate students. The KTH is divided into five schools where each school comprises several departments. The departments that have participated in the research into ECP belong to the school of Chemistry & Chemical Engineering and the School of Engineering Physics. The departments are Chemistry, Polymer Technology and Physics.

Department of Chemistry: In total there are 120 scientists, graduate students and technical staff at the department, which is divided into five divisions. The division of our interest is *Organic Chemistry*. During the 1980s research on ECP was performed by a small group of researchers.

Department of Polymer Technology: In the beginning of the 1980s the professor at this department showed some interest in the area of ECP. But the only research that has been done within the department was performed during the period 1986-1988.

Department of Physics: The department of Physics consists of 12 divisions. When research on ECP started in Sweden, several of these division were interested, viz. *Applied Physics*, *Physics 1*, *Physics 3* (later *Material Physics*). Their interest waned after some years except for two postgraduate students at Material Physics. They were active in two subjects, one of which was ECP, during 1984-1992.

Chalmers Institute of Technology (CTH)

At the Chalmers Institute of Technology (CTH) there is about 8 500 people, studying or working. There are around 1 300 teaching or research staff. The departments at CTH are divided into nine schools. Within each school there are several departments. The total number of departments is more than one hundred. Research into ECP is carried out at the School of Chemical Engineering. There are fifteen departments within Chemical Engineering and the departments of interest to us concerning ECP, are the Department of Organic Chemistry and the Department of Polymer Technology.

Department of Organic Chemistry: Five different areas are studied at the Department of Organic Chemistry. The staff consists of 26 people. Of these just two are doing research on ECP, Mats Andersson and his PhD student. Their research project is about Polythiophene and is called ”Electrically conducting polymers for light-emitting diodes”. The project is a part of another larger project and is being carried out in collaboration with Prof. Thomas Hjertberg and his research group at the Department of Polymer Technology, CTH. Another research group that participates is Applied Physics at Linkoping’s University.

Department of Polymer Technology: There are nine people working at the Department of Polymer Technology today, six of whom are graduate students. Their research activities are concentrated to five different areas. In the area ”Interfaces in Multicomponent Material” they are doing some research connected to ECP. During the period 1992 - 1997 eleven PhD degrees and five Licentiates have been awarded at this department.

1980 – 1984: POTENTIAL LINKS

Conducting polymers are mentioned already in 1980 in a short notice, in the STU-archives, about a ”new type of material, which might get its commercial breakthrough in the 1980s”. In the notice it was mentioned that the research was very intensive and that companies in the US like IBM, Xerox, Bell and Allied Chemicals, and universities too were active in the area. It was also mentioned that there were still a lot of problems to be met in the new technology due to stability problems and the defractioning of polyacetylene. Very optimistically the notice asserted that the explosion of research had resulted in a wave of new polymers that had the similar, and better properties. [7]

Ericsson had started some activities on ECP, maybe as early as before 1980. Malmkvist at Ericsson was a post graduate student in physics, and the interest was of a strategic kind. They visited some of the laboratories in the U.S. and were impressed by the speed and the range of efforts that was being put into this field of research. Ericsson expected that the STU would take responsibility for this type of pre-competitive research area, and they were especially keen on establishing networks of researchers in order to strengthen the capability of research in the small country of Sweden. In comparison with the large and interdisciplinary laboratories in the U.S., Ericsson’s home country was weak and small-scale in its efforts. The main problem, though, was that the STU agency was inflexible. Ericsson wanted fast moves, but the STU took their time.[8]

The first STU-meeting was held in November 1982, after almost three years of activities in companies and at universities.[9] The potential for practical use in electronics was said to be the main reason for a program initiative. The STU-representative presented a list of projects that were in progress within the area of organic materials in electronics. NFR supported a project at Linkoping University, (IFM) on ”Conducting polymers” and at KTH there were three different projects on organic metals, liquid crystals and optical materials. Furthermore, an NFR-initiative for a center for semiconductor research was mentioned where it could possibly be included. The group decided to go forward with an invitation to LiU/IFM, KTH Organic Chemistry and Polymer Technology, and CTH Physics Department.

At IFM research was organized in a multidisciplinary way from the beginning. Professor Lundstrom, coming from CTH in Gothenburg, started at the Applied Physics laboratory in 1978.

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[7] STU-Archive (Ragnarsson) 1980-04-17,

[8] Source: Interviews, August 1997.

[9] The protocol was written by the Ericsson engineer and post graduate student, Hans Malmkvist, on a paper with the Ericsson logo. Jan Bergman (KTH) and Ragnarsson (STU) were also was present at the meeting. In the STU/NUTEK archives we have not found any materials from this activity, but Mr Ragnarsson at NUTEK kindly invited us to explore his personal archive and there we found the material reported in the following section.

At CTH he had started experimental work on organic substances and their electrical conductivity (e.g. chlorophyll). In 1975 he was visiting researcher at IBM and came in contact with Jerry Corker. In February 1980 Lundstrom sent in a proposal for a pilot project on thin films of conducting polymers to the STU.

The recruitment of two guest researchers was part of a conscious plan to underpin a larger long-term proposal to the NFR and their program for energy-related research. The NFR-proposal was focused on catalytic reactions on metal surfaces and photoelectric properties of organic thin films. Within the NFR-proposal, Lundstrom applied for funding of a guest researcher in surface spectroscopy and physical chemistry from the Arrhenius laboratory in Stockholm. Lundstrom seems to have had a rather ambitious plan for research in this area as early as in the beginning of 1980.

In June that year the Swedish Academy for Engineering Sciences arranged a symposium on the subject ”Plastics – futures conductors?”. STU helped with the financing. The well-known researcher Alan MacDiarmid from the University of Pennsylvania visited Sweden and gave a lecture on his doping-techniques for enhancing conductivity and the potentialities of this from a commercial and usage point of view. In addition Dr G Brian Street from the IBM Laboratory, San José, talked about technical applications of the new technology and Ram B Roy (Studsvik, Sweden) gave an ECP-lecture on impressions from an international study tour.[10]

It is not known what role the IFM-group played for this seminar, but is probable that it was the starting point for the establishment of an interdisciplinary group at the KTH. Thirteen days after the IVA-seminar they sent in an application for travel expenses for a conference to be held in Copenhagen on ”Low Dimensional Synthetic Metals”. The motivation was that researchers at KTH had formed the above-mentioned group to study ECP. The leading researcher in polymer technology at KTH, Professor Bengt Ranby, visited MacDiarmid and Prof. Heeger in the US in August. Later in October Ranby, Assistant Professor Ahlgren from the Organic Chemistry Dept., Hans Malmkvist from Ericsson (and the Applied Physics Dept. at KTH) and others in the group sent in a proposal on ”Organic metals”. There they offered to set up research on polyacetylene and radical salts. In their application they mentioned that the Swedish firms ASEA, Ericsson and Nitro-Nobel had shown some interest in the area and that they had a co-operation with Ericsson. In Sweden they announced activities together with researchers in Uppsala and internationally they mentioned the US and France (Montpellier).

STU funded the project although expert advice (taken from a Government Research Establishment) had turned it down. Thereby STU was responsible for two research groups and gave each of them SEK 300–500,000 per year for six years. The IFM group seems to be a bit better financed as they also received funding from the NFR energy program.

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[10] IVA-report No. 183. Stockholm 1980.

Monodisciplinary and isolated groups?

It seems worthwhile to discuss our research questions, networking and interdisciplinarity, for this period in direct connection to this historical passage. The reason for this is that the context for these aspects changes over time due to new features of the technological and institutional settings.

As already mentioned, the Applied Physics laboratory at IFM called themselves an interdisciplinary group from the very beginning. Although directed towards physics research they had electrical engineers, chemists and biochemists in the laboratory. But, at the same time, they had no experience and no ability to synthesize polymers. There was only one chemist in the group.[11] As a consequence, they had to concentrate their polymer research on polypyrrole (and other semiconducting or conjugated polymers), substances they could produce themselves through electro-chemical processes. From this they experimented with the materials from a number of different angles and in several routes of discovery, which seems to be either fundamental and/or applied science. This work included experiments on thin film growth polymers and interfaces between metals and semiconductors, especially for solar cells. Quickly they managed to produce three patents, of which the ASEA company took one. In summary we can describe the IFM-group as working inside not one, but several, trajectories of the ECP-”paradigm”.[12]

There are few, if any, indications of a more substantial interdisciplinarity of work in the IFM group. They were physicists and they worked with new materials without substantial support from chemists. The reason may have had to do with a lack of competence. Instead they expanded their competence in physics through the recruitment of an American researcher, William (Bill) Salaneck (from Xerox and Pennsylvania University), who, in 1983, became professor at the IFM Laboratory for Surface Physics and Chemistry (IFM-SPC). Salaneck had published together with the founding fathers of the ECP research area – Heeger and MacDiarmid.[13]

The laboratories at IFM (IFM-SPC and IFM-AP) started an intensive co-operation, and Salaneck’s competence gave the AP-group a new strength. In particular his knowledge of photochemistry and photophysics, and the relevant instruments (photoelectron spectroscopy) for this, enabled the group to receive renewed funding from the NFR and new instruments from FRN (MSEK 1.7).

Our impression is that there were tendencies towards interdisciplinarity in the IFM group but the level of integration between physics and chemistry was not that high. The physicists drove the

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[11] Bjorklund was financed by industrial grants (ASEA)

[12] It is typical that the IFM-group in a conference report from 1982 (from les Arcs, France) voiced their criticism of the polyacetylene trajectory, due to its low level of stability, see Erlandsson, Inganas & Nylander, IFM-report 123/1982, p. 10: ”The problem seems to be neglected by most of the researchers in the areas and was not discussed at all at the conference. It was mentioned only in passing by some speakers. Talk in the hallway with representatives from industry revealed a deep level of scepticism regarding the problems with instability.”

[13] Salaneck also had publications together with such names as Steer (IBM Res. Center), Epstein (Xerox), Thomas (Pfizer Pharmaceuticals), Ritsko (Xerox), Clark, (Durham),

scientific and technological work. The group also concentrated their efforts on polypyrrole (PPy) and electrochemical processing of polymers. The IFM group seems to have been eager to consolidate their group(s) and did not put too much emphasis on networking activities.[14]

Let us compare the LiU-group with the KTH-group. Four professors from different departments at the Institute signed the first KTH applications. None of them were immediately interested or directly active in the actual area. ECP was but one of many potential areas where Ph.D. students and assistant professors could make an input. The STU program managers seem to have been a little suspicious of the KTH proposals and they turned the third one down demanding a revised proposal. After that, the group in Stockholm was accepted and was funded from STU for a period of six years in total. From what we have found there are no indications that the group was funded from NFR.

Mainly the KTH-group consisted of researchers from the chemistry departments and therefore they were able to produce conducting polymers by themselves. From the beginning, or quite early on, they decided to go along the polyacetylene trajectory. They thought it would be possible to produce higher conductivity and, at the same time, concentrated their efforts on the problems of instability. They had applications in mind as well, mainly in batteries and electronical devices, but there seems to have been much more typically trajectory-driven work at the KTH. They managed to produce a high conductivity in PPs quite early, but after that they did not achieve any substantial success in their work. Moreover, they wanted to perform research on crystalline materials, another ”organic metal” (cation radical salts), which might have had a fragmentary effect on their work.

The number of publications from the KTH-group was low during the period 1981–1986. They applied for only one patent and seemed to lose personnel, and/or had a hard time recruiting new researchers.[15] The IFM-group had a more positive development in their publishing activities. While the KTH-group had 13 published articles up until 1986 (and only six of them on ECP), the IFM-group had 32 published papers (and five patents). Of course, during this phase and in this respect Salaneck was instrumental.

Another difference between the both groups concerns the relation to industry. The IFM-group had contracts with ASEA and Ericsson. These contacts, tight or lose, had an effect on the STU program officers. If not too impressive, they were at least convincing and gave promises of more in the future. The KTH-group had no money from industry, but they had contacts with SAB-Nife (later Nife-Junger) and were given the opportunity to use some of their instruments.

None of the groups was extensively extrovert in their strategies. Both had guest researchers from abroad, and to some extent they had managed to establish permanent working relations with one external research group each. But, at the end of the day, the ECP research was national and without co-ordination.

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[14] See note above. To that list can the following visitors be included: Gibson, Duke, Rice, Conwell (Xerox), Pireaux (Belgium), Skotheim (Brookhaven), Mele and Ford (Pennsylvania Univ.) Pochan (Eastman Kodak U.S.), Tanner Univ. of Florida).

[15] From STU Archive and Interviews.

1984 – 1988 NETWORKING IN PROGRESS

In 1983 the company ASEA, one of the largest firms in Sweden, housed a seminar on conducting polymers where professor Alan MacDiarmid was invited as a speaker. The IFM-group had contacts with this company and we have been told that Professor Lundstrom, the head of that group, had a chair in ASEA's research advisory council. Assistant Professor Olof Wennerstrom at the Dept. of Organic Chemistry, CTH, attended the seminar and became interested. Wennerstrom's main interest and capability was as a theorist. One year after the seminar, Wennerstrom and applied for funding of an STU-project "Search for organic conductors". The proposal was quite general in its character and, mainly, they wanted support to build a new research group in the area. The first application was turned down, but STU gave them a small grant, after a revision of the proposal. In the next version they underlined that they had established collaboration with the IFM-group in Linkoping: "One example is polyaniline on which we have started a co-operation with the group at Linkoping University. They had been in contact with MacDiarmid at Penn. Univ. as well, and again, this shows the importance of that name. All the groups in Sweden had contacts with him, but the IFM-group had published together with this leading researcher.[16]

The ASEA initiative led to new contacts and this must be said to have had a positive effect on the research. Now the IFM-group had contact with organic and polymer chemists who were interested in the same type of research as themselves. That is, the CTH-group also wanted to do research on heterocyclic polymers like polypyrrole, polythiophene, and polyaniline.

One of the reasons for the CTH-group entering the area of conducting polymers is probably that the STU had a plan to set up a framework program for this field of research. The informal committee, which was mentioned above, managed to come to an agreement on what kind of program and which directions that should be supported. Ahlgren from KTH wrote a short paper on polyacetylene, stressing the possibility of using composites of different polymers to handle the problems of stability, and mentioned their plan on ionic radical salts as well.

Lundstroms paper was much more instructive and started with a whole page on possible applications for devices in the future: batteries, electrostatic screening, microwave absorbers, photoelectric chemical cells, corrosion protection, optical memories, displays, large-scale electronics, catalytic converters, chemical sensors, electronically-steered membranes. He also gave a description of where the Swedish researchers were located compared to the research front. For hetercyclic polymers and structural analysis of these polymers, Sweden was behind the front, and should try to come closer; in spectroscopy and some other areas Sweden was well ahead of the

[16] Hjertberg had a project on solid state NMR analysis (STU dnr 80-03524) and that was probably what they did for the IFM-group when they had their first contacts.

front. For possible future collaborations Lundstrom mentioned all the universities in Sweden, KTH, Lund (organic chemistry – two researchers), Uppsala and Umea. Lundstrom underlined the importance of good contacts with industry and had the impression that a framework program would be instrumental to this end.

In the final remark Lundstrom expressed his opinion that the area was undoubtedly of general interest and that the eventual commercial potentialities would show during the next five years. If STU funded a framework program then Sweden would manage to follow other countries in the ongoing technological race. Hans Malmkvist, at Ericsson, also wrote a short paper on possible electronical applications. On the basis of these papers the STU program officer presented a proposal for a framework program entitled ”Conducting polymers” in November 1983.[17]

The STU policy for the framework programs was that grants for university-based research should be on a long-term basis. The other form of grants was called projects. The long-term contracts were supposed to have both quality and relevance and the STU themselves saw no conflict of interest between those two goals. From the STU perspective the agency was responsible for identifying areas of interest for the future industry in Sweden. That was why they wanted to support university research. ”Quickly”, if needed, they should have resources for an intensified establishment of new competence in specific areas of research.[18] At the same time the industrial relevance was of crucial importance for STU involvement in a framework program. During 1982-83 they evaluated the industrial ”anchorage” of six framework programs by asking whether the industrial representatives in the committees had the ability and competence to diffuse results from the programs. The consultant who investigated these questions came up with positive answers, and the STU decided to go on with further developments of the industrial anchorage and more precise expectations of the representatives.

This policy was controversial within the scientific community. Researchers came up with criticisms of this policy because of the risk that relevance would direct the funding away from areas where research was of high quality, but industrial interest and competence was low. Because of that a discussion started on establishing a research council function inside or outside of the STU. After a short time a STUF was established within the STU. The F stood for ”scientific research” and depicted a research council function. In 1990 this function became the TFR.[19]

The STU policy had effects on the management of the ECP area. To start a framework program the agency had to have industrial representatives who were dedicated and interested. Ericsson’s engagement by this time was low – Malmkvist got tired of the slowness and went over to other areas. Unfortunately there were no other supporters of the field. This made it difficult to establish a framework program. To achieve a more dedicated industrial co-operation, the program officers at STU turned to the ASEA company, which seemed to have an economic interest in the area. It is said that the company needed a reorganization of their research division. A new

[17] STU Archive Ragnarssons papers

[18] STU-perspektiv 1983, 1981 och 1979, see also Weinberger (1997) passim

[19] STU-perspektiv 1983 and Weinberger (1997).

proposal for a framework program was written rapidly. Surprisingly a new area was included in the program. It was called ”Polymer Electric Properties” and was directed towards polymers as insulators, especially polymer degradation in electric fields and chemical changes in polymers used as electrical insulating materials. This new direction was fully in line with ASEA’s company profile; there was already a research group at ASEA RESEARCH (twelve persons) within that field. Now the company needed contacts with universities to get a broader knowledge base, especially in chemistry.

In the new program proposal the authors could not avoid expressing their own doubts about the possibilities. They wrote: ”It might be the case that research on conducting and insulation polymers, in part, can be co-ordinated.”[20] The proposal did not come to an implementation in the usual STU forms. Instead the agency continued its co-operation with ASEA and started a new type of grant, which was called a ”project package”. This package consisted of six different projects for the year 1984/85, four of which were financed by ASEA and STU, respectively.

Project No 1 was an ASEA-led project on polymer degradation (ASEA’s Arne Hjortberg was principal investigator). This project received SEK 400,000 from STU. Projects no. 2 and no. 3 were on the same subject (non-ECP) and gave a funding of SEK 350,000 each to KTH and CTH polymer technology departments. Project 4 went to the IFM-group (Lundstrom and Salaneck). The project was called ”Control of conducting properties of polymers”. STU gave SEK 175,000.

The IFM Applied Physics group also received another solely STU-financed project (SEK 300,000 for ”Conducting polymers”) and the KTH, including Prof. Ranby, received the same amount of money as well. In the two latter projects, ASEA did not contribute any funding. In total ASEA managed to get SEK 925,000 from STU for their insulators projects, and the research on conducting polymers was confined to SEK 600,000. ASEA’s Arne Hjortsberg also became chairman of the informal steering group.[21]

The CTH-group was not included in the package. They had to wait a long time for a response on their application. In May 1985 they got money for two years (SEK 350.000 per year) and the money came from the newly established STUF, the research council inside STU.

The STU ”initiative” in 1983 had, after three years of informal networking, resulted in a Pyrrhic victory. The research field ECP had not been institutionalized during the process. There were no dedicated industrial interests and without these it was almost impossible to receive long-term funding. In the project package grant there were no implicit obligations in terms of time for funding. In this respect there was an insecure period during 1985–86. The field was not approved as a strategically interesting area from the point of view of Swedish industry. Even if the number of researchers was growing, it was questionable whether there would ever be enough money for these new young researchers.

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[20] STU Archive Ragnarsson 1984-03-05, p. II, 2. As our archival sources does not give us full information it is impossible to exactly say when the redirection took place. It might be the case that the ASEA-focused proposal was produced only a couple of week before the committee had their meeting in March 1984.

[21] STU archive dnr 84-3777.

How to explain why the STU program officers chose to go along the ASEA line? At this time STU had an ambitious plan for framework programs in basic engineering and generic technologies. This was an orientation away from the short-term project grants and with the more coherent programs they wanted to raise the performance of research groups. Partners from industry was not compulsory, but was indeed a significant argument if a program officer wanted to start a new framework program. The conclusion is simple: Firstly, the program officer in charge of this specific field of research had not enough strength to convince the agency of the need for a program in this field. Secondly, the implementation of the policy for framework programs was done in a mechanistic manner. One of the means of getting higher performance (industrial contacts and networks) became the main goal of the whole operation.

The Nordic ECP Network

The problems connected to the program created a state of insecurity, which motivated new efforts in networking activities for financing of research. One of Wennerstroms postgraduate students, Bengt Thulin, had a position at IVA and had been a partner in some related activities. Moreover he was knowledgeable in the area. He was also one of the representatives in the Nordic Industrial Fund (NIF), a joint program for industry-relevant research in Scandinavia. If there were companies that wanted to join in for knowledge development in a specific area, then the NIF could support the activities for a period of up to two years. The NIF initiative rested on the extent of industrial interest from Nordic companies, and Thulin and his Norwegian partner (Boler) managed to involve Norsk Hydro (Norway) and two Finnish companies, Neste OY and KSV Chemicals. These activities resulted in new money and new scientific contacts for the three Swedish groups.

We have already noted that the CTH-group had contacts with both of the IFM-groups. The contacts were not permanent, and in order to establish a working relation between the both groups someone had to push them together from outside. In this respect the NIF-initiative was instrumental. Thulin visited Linkoping in November 1985 and after that the sporadic contacts became more than isolated events. This characterization of the CTH and IFM relationship is probably a correct description of Nordic relationships in general. One of the interviewed researchers said: ”There was an informal network before the NIF-project, but after that it became more of a formal network.”[22] This is especially apparent when it comes to publishing habits. Not before 1987 can one find co-publishing between members of the Nordic network.[23]

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[22] Interview 970523 p 2

[23] One of the first events when the Nordic network met and was gathered was probably the Vadstena conference in August 1986. One hundred participants from all over the world (fourteen countries) gathered in this small town in the middle of Sweden. The initiative was taken by programme officers at STU in 1983 and they convinced Salaneck at IFM to apply for a joint NSF (US) and STU conference project. The NSF had to withdraw their grant, but with support from NFR, companies and the IFM the conference was realised. Of course, MacDiarmid was one of the key speakers. Heeger and Epstein visited the conference. Osterholm from Finland and Bechgaard from Denmark were there, as well. IFM, CTH and KTH had a large representation.

It is unclear which amounts of funding the NIF-project gave to the Swedish researchers. The Nordic network had to deliver a proposal where all the activities in the different countries and at all the departments/laboratories were described. In retrospective interviews, informants underline that the co-ordinator (Hjertberg) did tremendous work to make one project out of seven or even more different projects (or trajectories). At this time the first processable ECP (polythiophenes) was introduced and became one of the main interests for the CTH-group, who focused their research on problems with the synthesis of new polythiophenes with substitutes, which made them soluble, processable and/or orientable. An informed guess is that Neste OY had a great deal of interest in these aspects of ECP. ”The goal of the project is the development of low bandgap polymers amenable to polymer processing”, the IFM-AP-group wrote in their Activity report.[24]

The IFM-SPC-group was now established in mass spectroscopy (i.e. a photoelectron spectrometer) and other types of instruments that they managed to build in their laboratory (e.g. an N_2 laser for laser-assisted UPS on polymer film). These specialties made the laboratory an interesting partner for other research groups, who could get new results through co-operation. This also had one considerable consequence for the ability to keep at the forefront of research. The group became unaffected by the change of trajectories in the ECP area. Over time the possible applications shifted a lot and new materials came all the time. One such shift that took place in the late 1980s was from polythiophenes to polyaniline. Not that the interest in the former totally died out, but when certain properties become more interesting than new (or older ones), polymers come to focus for most of the research. If you have an assemblage of instruments of the kind that the SPC-group had built up, then you have a higher degree of autonomy. It is typical that during this period they also had a rather extensive exchange with MacDiarmid and published several articles together with this world-leading scientist.

Therefore the SPC-group was certainly of strategic importance for the other IFM-group in Linkoping. Almost all of their proposals were written as joint projects between the two laboratories. In effect the group had a potential for both more basic science and more applied science. They continued to put an emphasis on possible applications in their proposals to the STU. In the middle of the 1980s Inganas moved towards the electrochemical trajectory using spectroscopy and other methods to study interfaces. This line of research – electrochemically generated conductive polymers – was a tradition at Brookhaven National Laboratory where one of Lundstroms PhD-students (Inganas) spent his postdoctoral year in 1985.

The IFM-groups continued in their efforts to produce and synthesize new polymers. Around the year 1985 the group discovered that it was possible to prepare ECPs by chemical vapour deposition (CVD) and tried to patent this method. With this line of research they were not forced to have a more intense relation with organic chemists. As long as they kept out of polyacetylene and polyaniline, they could manage without the support of other departments. In the middle of the 1980s they had started to receive polyaniline from MacDiarmid and that is all that is mentioned before they got into the NIF network. The co-operation within the network, especially with Osterholm at Neste OY, led to the discovery that polyalkyltiophenes were termochromic,

[24] Activity Report 1986-87, p 5.

i.e. they change color with temperature. Twisting of the polymers leads to changes in electronic structure and optical absorption. This phenomenon underpinned the interest for extended collaboration with researchers in quantum chemistry. IFM contacted the Brédas research group in Mons, Belgium.

The Nordic Network started to publish articles together. The CTH chemistry-group primarily related to the SPC and AP groups started an intensive exchange with the Neste OY laboratory in Helsinki. In some cases all of them did work related to each other's and as a consequence there are some articles with three or four departments/laboratories involved. A strict bibliometric approach would lead to the conclusion that networks had been established and that the interdisciplinary aspects had grown considerably by this time.

At least one of these proposals is open to certain objections. Regarding networking activities it seems obvious that the Nordic network formed a non-hierarchical structure (Mizruchi) where at least Neste OY, VTT, IFM and CTH came to work in close contact with each other. KTH had more contacts with KSV Chemicals, but this collaboration never really developed into real co-operation. After some time the Finnish company ceased to co-operate with the Swedish researchers.[25]

In the other part of the network, activities became more and more intensive. Neste OY came to be a supplier of polymer materials in large quantities and as a consequence, the researchers, for the first time, got the opportunity to use their experimental methods on materials that were cleaner and comparable. Before that the Swedes had had to rely on smaller amounts and very seldom had the chance to use the same sample for different lines of experiments.

What about interdisciplinarity? Within the conception of Schmoch et al (1996) described above, the relations during this period can be outlined in terms of a transfer from monodisciplinarity to pluridisciplinarity, i.e. co-operation without co-ordination of different disciplines in one project. Our impression from interviews and written sources is that user-supplier relations characterized the collaboration between physicists and chemists to a large extent. One group ordered a specific type of material or experiment on a material and the other group delivered. It is unclear to what extent this co-operation led to a more elaborate discussion and exchange of perspectives. The languages were different and there were a lot of problems connected with this. However, the subject ECP had at least one specialized journal where ”inter”disciplinary articles could be published (Synthetic Metals). But the number of authors and their institutional affiliation are probably not a very good denominator for the level of interdisciplinarity in the field. Our analysis on this point can be summarized in terms of a growing interest in co-operation between physics and chemistry, but the impression is that the researchers had severe problems with communication during this phase.

[25] Interview KTH

1988–1997 NETWORKING IN TROUBLE

At last, in 1987, the STU agency decided to transform the ”project package” into a framework program. As has already been mentioned, these types of concentrated efforts in specific areas of research were meant to enhance ambitions and to co-ordinate the initiatives taken. In particular the STU wanted to involve external contacts, especially companies, in the programs to secure support for the state agency and its policy.[26] Another pillar of the program was that the funding of research could be made at a level that would guarantee a long-term mobilization of actors and competencies.[27]

That was the policy. When the framework program for ECP and Polymer Electric Properties was set in motion, it was one of smallest STU programs. It was given SEK 3,000,000 per year (400-500,000 US Dollars), while the average program received SEK 8,000,000 per year. As the construction with a blend (or mix) of polymers as conductors and insulators was continued, the amount of money for research on ECP was not very large. Instead it might have had negative consequences as all proposals in the area were transferred to the framework program steering group, which made it hard to get money from the normal project grants.

There is a lack of sources about the STU framework program in the NUTEK archive. The program officers' papers and other written sources from the group meetings or other material from the STU have disappeared. From our oral sources we have the impression that the program was badly managed and that the company representatives, except the one from ASEA, was uninterested in the matter of ECP. The group also included representatives from Nitro Nobel and Kema Nobel. The academic professors were Bengt Ranby from KTH (Polymer Technology), Bill Salaneck (IFM) and Olof Wennerstrom (CTH).

After a while it became obvious that the grants were divided between the three universities in order of their academic strength in the polymer business. This gave Stockholm a huge advantage, but this principle did not render the ECP-group at KTH any money. The KTH-group were turned down, while other aspects of polymers, their electric properties as insulators and polymer degradation in electric fields, were given funding. According to some of our informants, the steering group for the program experienced that the STU officials in their decisions did not follow their recommendations on funding. We have also been told that the chairman of the steering group left his position after a couple of years in protest against the management of the program. One of the leading researchers from the IFM-group cannot even remember the program when asked about

[26] The framework programmes can be interpreted as an instrument to compensate for the loss of support that is a consequence of the diminishing corporatist traits of the political regime in Sweden (c.f. Sandstrom 1994 and Sandstrom 1997).

[27] STU perspektiv 1989.

the funding during this period. IFM, though, managed to get grants from the program some years after the program was started.

When the framework program was finished, an international review group spent a week in Sweden and visited twelve research groups in five establishments.[28] The evaluators produced a typically neutral report and added some small comments on the need for a continuation of the program. They did not point to the diversified matters in the program. The exercise was done in 1992 and at that time optical effects and devices were the proper thing to stress in recommendations. The part of the program that was directed towards dielectric properties was, according to the evaluators, badly managed and without co-ordination.[29]

The continuation of the support from Neste OY to the IFM-group was important. The IFM-groups received money for one postgraduate student each. NFR also gave money of that order to both of them. People at the IFM (Theoretical Physics) received grants from 1989, both from the STU framework program and the NFR. The CTH-group obtained approx. SEK 500,000 per year from the STU (in 1988–1989 they had an additional SEK 500,000). In contrast the KTH-group, which did not have any researchers on permanent tenure, only received a small grant, SEK 250,000, until 1988. The group dispersed, but Svante Soderholm continued the work, in collaboration with Jonas Hellberg, the former with STU funding and the latter with NFR-funding.

In summary, the IFM-groups in Linkoping grew quickly during this period. The SPC-group, who had a chair, was successful. They continued in international collaborations and built up long-term relations, e.g. with quantum chemist, Brédas, in Belgium. We will come back to that strategy later.

The AP-group as a case is interesting as it shows the importance of tenure positions at the university. In 1987 the leading researcher (Inganas) was offered a position as lecturer at the department. This was made possible by block grant funding from the STU to the laboratory for Applied Physics. Professor Lundstrom had received very good evaluations for his work on biocompatible surfaces and along with the framework program related to that area, the STU decided to support him with a block grant.[30] This gave Inganas a tenured position.

The following year, 1988, he received a position funded by the faculty. With this type of funding of his own research and his administrative and management work he could take on postgraduate students and guest researchers more easily. He did not need to bother about his own financing. From 1988, his group consisted of 6–10 persons.

The IFM-group, with three (or four) laboratories, became large. Along with the AP-group, there were two more supervisors and research leaders in the ECP area at the IFM. The SPC-group, who had more funding, was a bit larger, and Theoretical Physics also started a small group of almost four young researchers. In all, there were as many as 15–20 ECP-researchers, mainly physicists, at the IFM.

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[28] Feast (Durham), Kobayashi (Japan), Roth (Stuttgart) and Sletbak (Norway).

[29] STU Report R 1992:59.

[30] At the same time the STU criticised the Ministry of Education for not giving sufficient basic funding to the Institutes of Technology and colleges, c.f. Weinberger (1997).

The CTH was smaller and there seems to have been a resistance towards fast growth of personnel. Basically, this was due to a personal choice of the leader, Wennerstrom, who was not as expansive as his partners in Linkoping were. He became a full professor in 1992. Thomas Hjertberg was a more active entrepreneur, but he soon went over to other areas of research.

The STU commitment to the ECP-area disappeared after the framework program was finalized in 1992. No new initiatives were taken after that. During the framework program period Inganas also received funding from other framework programs (Micronics program) headed by NUTEK, which has lasted until 1996. However, after 1991, Inganas has not been granted funding for new projects on polymers from that agency. Instead the TFR and NFR, the research councils for engineering sciences and natural sciences, have provided him with new funding. The same is true for Salaneck and the CTH-group.

Research areas during the 90s

The CTH-group had a contract with Neste OY for a five-year period after the NIF-project. They continued their work with stability and durability (and orientational) problems. This lead to a number of publications together with the IFM-groups and the Neste researchers (e.g. Osterholm), where the theoretical understanding of thermochromism and undoping of polymers was developed. In this context both groups, together with the Finnish partners, developed new techniques for polymerization which, among other things, led to applications such as coating polymer surfaces with very thin layers of conducting polymers, suitable for antistatic protection.[31]

The work in the AP-group gave such applications as ”smart windows”, i.e. electrochromic devices which could be switched between dark and transparent states based on polytiophenes and polypyrroles in combination with optically transmissive counter electrodes. The collaboration with the Finnish group also led to the so-called ”polymer luministor”, an optoelectronic polymer device analogous to the polymer field effect transistor.

The AP-group continued in a device-oriented style of research. But in applications to the STU they more seldom underlined that new possibilities were to come in a short time. In several projects they developed aspects of polymer electrochemistry. If they did not manage to raise money from the ECP framework program of the STU, they instead got funded from the ”Micronics” program.[32] This work was related to the interest in polymers as actuators, ”electroelastomers”, and as ”micro muscles” During the 1990s the group, like many others after the discoveries of Friend, directed their research towards optical aspects of polymers (light-emitting diodes, LEDs).[33] In 1994-95 they had a major success with a total of three reports

[31] They got a patent together with UNIAX. We have been told that UNIAX was born when people from Linkoping introduced Neste researchers to Heeger et al at a conference in the U.S. in 1988.

[32] STU info 776–1990, p 32-33

[33] In 1990 the Cavendish Laboratory at Cambridge University presented the first light emitting diode. Later that year researchers at the California University presented the same results.

published in the elite journals *Science* and *Nature* about polymer LEDs, nanoLEDs and micromuscles.

In the LED area the AP-group and the CTH group extended their collaboration during the 1990s. In the 94/95 Activity Report from Linkoping the AP-group wrote: ”More polythiophenes have been arriving from our collaborators at Chalmers.”[34] According to interviews this co-operation has led to a deeper form of interdisciplinarity, where the researchers have a type of collaboration which can probably be termed ’transdisciplinary‘. There is more of a melding of disciplines even if this process has not led to a total melting pot. The disciplines are still there, but the researchers have developed a pattern of communication that goes beyond the usual crossdisciplinary co-operation. Together they design and discuss the synthesis of polymers and jointly they also do a large part of interpretation and analyses of experiments.[35]

The partnership between the IFM-AP group and the CTH-group is of a specific type and cannot be compared to others collaborations, e.g. with the synthetic group at Teltow in Berlin. AP has had a lot of co-operation with other researchers at other laboratories at the IFM, e.g. Material Physics as well as Device Physics. Their international co-operation, though, has not been that strong during the 1990s (see below for bibliometric analysis).[36] As a consequence of their breadth and interest in devices, they have tried to develop contacts with private companies. They have had projects together with Ericsson, but this has not led to any long-term contracts.

In 1997, finally, it seems as if things are changing. Major steps towards a commercialization of research in the ECP-area have been taken. With finance from Norwegian capital, a research centre is to be set up at the science park of Mjardevi, nearby Linkoping University. A total of fifteen researchers are, among other things, hired to develop several of the routes of research that was initiated in the IFM-group. The most important one is a new technology, called plastic memory, which is said to be on the market by the year 2000. The potential market should be very large as the plastic card is able to hold as much information as several thousands compact discs. The card might even come to replace the hard disk, RAM memory, and parts of the PC-processor. [37]

DIFFERENCES IN STYLES OF RESEARCH

Let us analyze the differences between the groups involved in the Swedish research on ECP. In the trichotomy of Law (1976) we would describe the IFM-AP-group as typical ”subject matter

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[34] Activity Report 1994/95, p. 12

[35] Source: Interviews.

[36] With an exception for the co-operation with Stubbs and Laakso in the beginning of the 1990s.

[37] Source LiteNytt 14/97, Interviews and Web sites.

specialists". The solidarity with the rest of the research community rests on the basis of a shared interest in a particular subject matter or problem. As a consequence they develop very close and personal relationships in their network. The number of meetings and the interchange between them and parts of the CTH group are very intensive. From this follows a higher level of interdisciplinarity.

In contrast, the IFM-SPC-group, are technique- or methods-based researchers. Their equipment is their niche. Through the development of instruments (e.g. photoelectron spectrometers, STM) the group becomes indispensable for a number of other research groups. With this specialty follows an affinity with more theoretical and formal researchers. The laboratory has, for example, had an extensive collaboration with Stafstrom (at the IFM Theory Group), Brédas (Univ. of Mons, Belgium), Wennerstrom (CTH), Freund (Bochum, Germany) and Lunell & Keane (Uppsala). They are, of course, not unaware of the devices and have tried to apply for patents as well, but more methodological patents than mere devices.

Interestingly, it is possible to explain a great deal of the SPC-groups international collaboration using this niche strategy. Their co-operations are almost exclusively with other researchers who complement the "chain of research". In consequence it should be possible to show that their research is used as a part of a device-oriented research in other countries, e.g. UK (Clark, Friend, Bradley) USA (Epstein, MacDiarmid), Finland (Osterholm), France (Schott, Froyer).

This said, it is necessary, at the same time, to note that the SPC-group cannot exclusively be described in the categories proposed by Law. The professor and his personnel have developed a certain expertise in polymer-metal interfaces. This field of research has shown to be instrumental in the European networks that have evolved during the 1990s as they have directed their efforts towards light-emitting diodes. This has created an ESPRIT program together with the UK, Netherlands (Philips), Italy and Belgium. Almost the same subcontractors have been involved in a Brite/EURAM project with the goal of producing working polymer-based LED for commercialization by the year 1997.

Many projects includes participators from Germany and France (Thomson CSF). Firms like Neste OY, Philips and Hoechst have provided funding to the group and one strong impression is that they have succeeded with their strategy for funding research. The ability to raise funding and to keep in contact with many research partners is shown by the active role in the NEOME network funded by the EU as an organization to promote the science and applications of molecular materials for electronics in Europe. The network has organized meetings, symposia and courses in the area of research, which is somewhat broader than the theme for this report.[38]

The level of interdisciplinarity in the SPC-group is hard to judge. If we apply the conceptual scheme mentioned earlier, they are mainly at the cross-disciplinary level, i.e. the research efforts are co-ordinated and to some extent there are exchanges between disciplines. The niche strategy can be one reason as to why the more integrated and transdiciplinary tendencies have not yet appeared.

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[38] NEOME ....Salaneck has been involved in TMR-programmes as well.

In contrast to this we are apt to characterize the IFM-AP-group and the CTH-group as moving towards a transdiciplinary stage. Typically they send their postgraduate students to laboratories where genuinely transdisciplinary work is done or they send them to institutes where they are supposed to work together with researchers from other disciplines.

The differences in style of research between the both IFM-groups can also be described in a more quantitative manner. In the analysis below, based on bibliometrical data, it is shown that both groups have separated during the 90s.

Dynamics of co-authorship networks

In order to find Swedish papers on conducting or conjugating polymers we used the Science Citation Index™ on CD-ROM 1991-1996. First we retrieved all Swedish articles. Then from this set we selected all papers containing the word stem ”polymer”. Next we selected papers written by some of the following Swedish researchers in the field:

From *Linkoping University*: Inganas, Olle; Salaneck, William; Stafstrom, Sven; Berggren, Magnus; Lundströn, Ingemar.

From *CTH*: Andersson, Mats R; Hjertberg, Thomas; Wennerstrom, Olof; Flodin, Per.

From *KTH*: Ranby, Bengt; Ahlgren, Goran, Sundqvist, Bertil; Bechgaard, Klaus. (Unfortunately, the list is not complete).

We have compared this search strategy with several others, for example using the word stems ”conduct” or ”conjugat”. However, using these kind of keywords we did not retrieve more than about half of the papers that were found using researchers’ names. Still, the set of papers used in the analysis below is preliminary and we plan to add a few other names, which will probably retrieve several more relevant papers.

We have also considered extending this analysis of research networks by looking at the citation behaviour of the Swedish papers. Such a study would yield:

· maps of authors citing each other (direct citations),

· maps showing the similarity of their reference list (bibliographic coupling)

· maps showing the knowledge base used by various groups of authors (using co-citations)

The analysis shown below should be interpreted together with interview data. The location of the interacting authors is approximate and the amount of co-authorshipÕs is indicated with the thickness of the lines connecting the authors.

In Fig 1 there are two groups, one from KTH, to the right, and a mixed IFM and Chalmers group. Several of the articles are institutionally co-authored and, consequently, people from different national and international locations may be on the maps. For example, the KTH cluster contains a number of Chinese authors who come from Univ. Sci & Technol China (See Table 1, which could be made as a map also, but the addresses have to be standardised first). Fig 2 describes the situation during 1994-1996, and it is quite obvious that there is a split in the large Linkoping/Chalmers group, while the KTH group is still not interacting with the others.

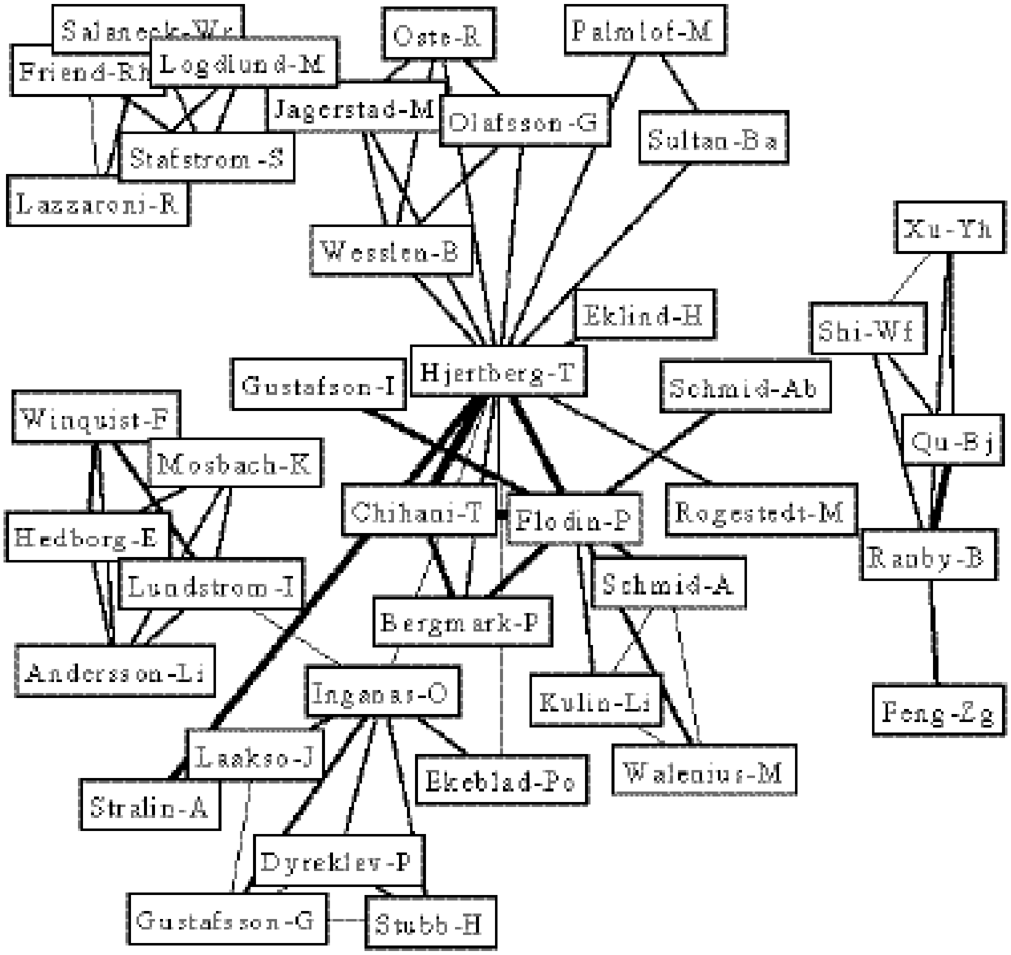

Fig 1. Conducting polymer co-authorship network 1991-1993

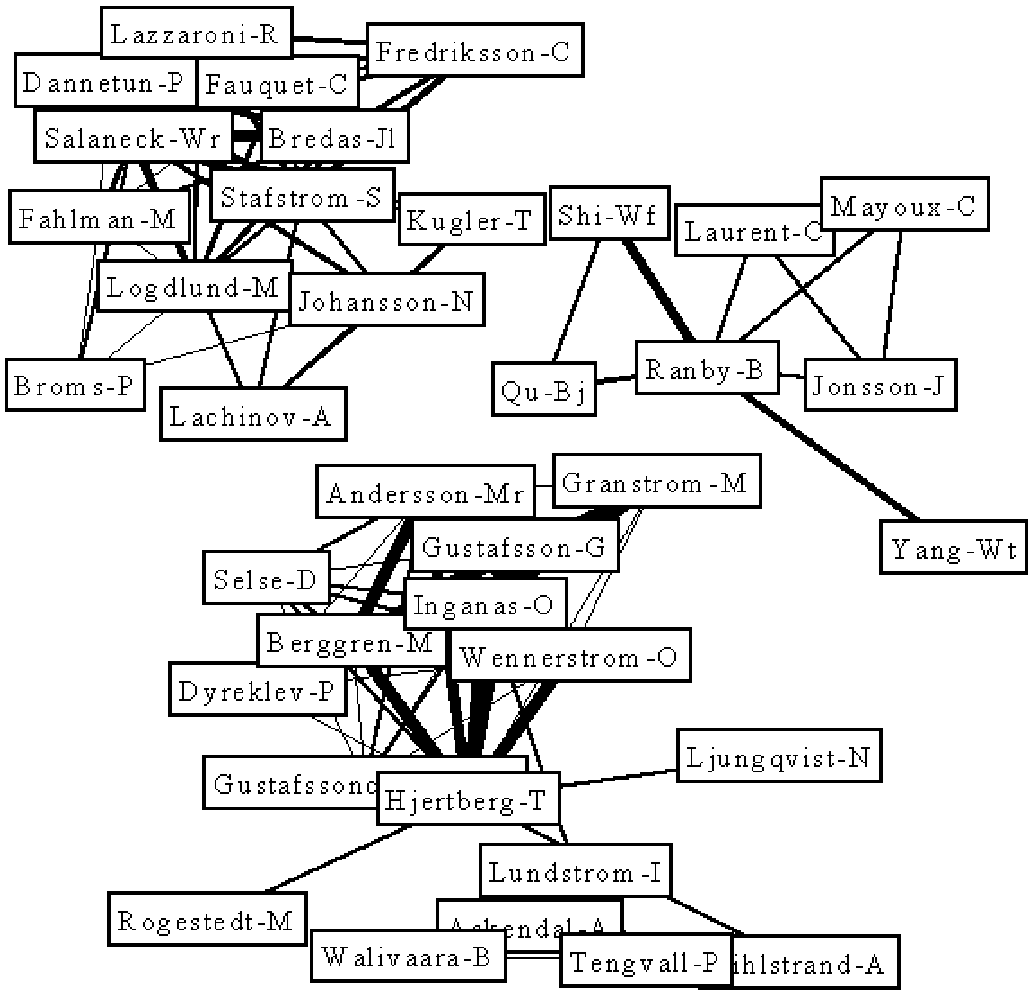

Fig 2 The Swedish conducting polymer co-authorship network 1994-1996

Table 1. The Swedish conducting polymer institutional co-authorships 1991-1996

Co-author-ships	**Salton´s Index**	**Authorships**	**Authorships**	**Collaborating institutions**
23	0.35	74	59	Chalmers Univ Technol - Linkoping Univ
11	0.43	59	11	Linkoping Univ - Univ Mons
9	0.12	74	74	Chalmers Univ Technol - Chalmers Univ Technol
7	0.48	31	7	Royal Inst Technol - Univ Sci & Technol China
3	1.73	1	3	Natl Acad Sci Ukraine - Umea Univ
3	1.00	3	3	Umea Univ - Umea Univ
2	1.41	2	1	Univ Marburg - Univ Paris 07
2	0.82	3	2	Univ Cambridge - Univ Durham
2	0.82	3	2	Linkoping Inst Technol - Univ Durham

2	0.43	2	11	Univ Marburg - Univ Mons
2	0.25	31	2	Royal Inst Technol - Univ Toulouse 3
2	0.18	59	2	Linkoping Univ - Univ Marburg
2	0.18	59	2	Linkoping Univ - Tech Univ Denmark
2	0.18	59	2	Linkoping Univ - Russian Acad Sci
2	0.18	59	2	Linkoping Univ - Lund Univ
2	0.16	74	2	Chalmers Univ Technol - Neste Polyeten Ab
2	0.16	74	2	Chalmers Univ Technol - Max Planck Inst Polymer Res
2	0.16	74	2	Chalmers Univ Technol - Lunds Inst Technol
2	0.16	74	2	Chalmers Univ Technol - Ecole Polytech
2	0.15	59	3	Linkoping Univ - Univ Cambridge

Note: Salton´s index is a normalized measure of co-occurrences, which divides the co-occurrence frequency of each pair with the square root of the product of the authorships of the two parties. This index is commonly used in bibliometrics.

SUMMARY AND CONCLUSIONS

Networks. There is no doubt that the ECP area in Sweden has developed through spontaneous networking activities, which to a large extent are dependent on personal relations and personal affinities. Personal friendship is the most frequent explanation for collaborations in our interviews.

From the very beginning Linkoping (the IFM group) has been the centre of research in the ECP area. Others have tried to enter it, but for different reasons, mainly due to scientific choices and/or organisational weakness, they have had to remain in the periphery. Linkoping had several advantages compared to others. At the time for the first discoveries, when the scientists entered the area, Linkoping was a newly established university, with a lot of young professors. The university chose a new form of organisation with large, multidisciplinary departments, which were all located in the same building. This ”localness” has generated a close relationship between professors of different specialities and between post graduate students as well. Other universities (the big five) all have their respective disciplines in separate buildings.

The IFM group had one disadvantage – lack of competence and experimental capacity in chemistry. To handle this they concentrated on a substance they could produce by themselves, polypyrole. This had two important consequences. First, they developed a specific competence which made them an interesting partner in collaborative work with other researchers/laboratories. This gave them an extensive network of international relations during the 1980s. They also recruited a researcher from the U.S. Second, they learned about a different trajectory than the route mostly taken during that time, polyacetylene, and that gave them an advantage later on when the major trajectory seemed to be a dead-end.

In 1985 IFM also started a collaboration with chemists in the CTH group, leaving the KTH group aside. The co-operation with the CTH group was expanded during the partnership within a Nordic network, mainly with Finnish companies and researchers. This gave the Swedes new and better materials, cleaner and larger amounts, which also made it possible to conduct comparative experiments on exactly the same material.

Exactly why the group at KTH did not manage to get themselves included in the IFM–CTH network is open to different interpretations. The first is that the competition during the first period led to a situation where both groups more or less fought over funding and ideas. The KTH trajectory was polyacetylene whereas the IFM followed another path, the polypyrole. This could have made it hard for them to co-operate as they had to fight when it came to funding. Another fact to take into consideration is that the STU agency probably found it easier to work with people from the physics departments than with organic chemistry. The polymer technologist in Sweden also had an in-depth relation to their industrial partners and none of them was interested in the emerging areas of electrically conducting polymers. A third explanation is that the STU agency was a weak actor in the field. The programme officers tended to rely on their relations towards their former supervisors and were weak in building up new relations in areas with a high level of insecurity. A fourth answer as to why the STU was slow in their actions, although people at the Ericsson company suggested fast moves and flexibility, is that the agency found it difficult to act in areas where there were no explicit firm initiatives.

The first networking activities were conducted by the IVA (with support from STU), and this certainly pushed the area forward. Really important networking, in the form of forcing groups of researchers to co-ordinate their efforts, was not done before the NIF took the initiative in 1986. While this did not last for long, it certainly started collaborations between Swedish and Finnish researchers that has had a long-term effect on the competencies and the capabilities in Sweden.

These collaborations resulted in articles whose authors have been cited on numerous occasions. The IFM- and CTH-groups had the honour of arranging the ICSM-92 conference in Gothenburg[39] and the following year Salaneck, Lundstrom and Ranby arranged a Nobel symposium in Sweden with a number of the best names in the area as key note-speakers (Heeger, MacDiarmid, Shirakawa, Friend, Feast, Brédas and Epstein just to mention a few of them).[40].The number of citations of the IFM-group in these state-of-the-art essays is quite high and this is only one of several indications of the good performance of the Linkoping group.

Although the agency for technical development, STU/NUTEK, had a policy which focused on networking as a major pillar of their programme, they did not manage to connect the different research groups in Sweden. Instead it seems as if the STU was detrimental to the development of the area. Most of the support went to polymers as insulators, although the actual programmes started as ECP programmes. We have found that the explanations for this are twofold: 1) A mechanistic, slow and anxious implementation of policy at the agency. Even though there were no private firms interested in ECP, firms with other interests were invited to join the programme steering committee. 2) Powerful academic actors in the polymer technology area took leading roles in the committee.

Our first conclusion is that there has been no national actor capable of co-ordinating the resources for research in Sweden. A spontaneous network has been built up based on personal relations. As a consequence the competence and resources at the largest technical university (institute of technology KTH) has not, or only to a small extent, been harnessed for the area.

The lack of industrial interest can be explained with reference to the character of the chemistry and plastics industry in Sweden. The sector is small and more concerned with the processing of bulk materials. The firms have no interest in products outside their specific niche. Applications of the scientific findings have not been likely in the short-term, and because of that the industry's policy is generally that the state should support basic and strategic science. The division of labour is strict in Sweden.

Interdisciplinarity. This aspect is closely connected to the organisation of research. The lack of chemical competence at the IFM has been a driving force for co-operation with other groups,

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[39] The International Conference on Synthetic Metals (ICSM) is the largest conference on elctrically conducting polymers.

[40] The conference resulted in an Oxford book volume where all of the distinguished researchers participated. In several of these essays the IFM results are heralded.

nationally and internationally. In the beginning the physicists could do without direct collaboration with chemists, but after a while they had to develop competence on their own and competence through others. Lack of synthesis chemistry was a drawback that the IFM group overcame through their co-operation with CTH and the Nordic network. Those more permanent relations had a stronger effect and gave momentum to the interdisciplinarity of the research in Sweden. The younger researchers who entered the area after 1985 have generally had less disciplinary boundary-making in their education, especially in Linkoping, and we have been told that they normally have contacts with people from other disciplines. For example the physicists in Linkoping try to send their post docs to chemistry departments in the U.S.

As long as the researchers do more basic science, there is not an instant need of interdisciplinary contacts. The different groups can specialise in their specific experimental techniques. From this fact interdisciplinarity can be interpreted as a consequence of the application-driven routes in the area of research. The nearer an application, the more you will need competencies form both physics and chemistry.

The type of interdisciplinary work that is often performed in laboratories in the U.S. is very seldom done in Swedish labs. In the conceptual scheme proposed by Schmoch, and referred to above, we would conclude that research in Sweden has been pluri- and crossdisciplinary in its character. The groups involved conduct mutual work on the interpretation of experiments and in the planning of research. At the same time there seems to be an elaborate division of labour between the groups and the disciplines. Even within one discipline we have found that there is an intricate division of labour. While some researchers develop their own specialities through competence in, and by obtaining, complex instruments, others develop their niche as generalist researchers who pick up results from others and join them together, often with applications in mind. Following Law (1976) we use the concept ”subject matter speciality” to depict the latter and ”technique/methods based speciality” for the former. One has to take this dimension into consideration to perform a complete analysis of the interdisciplinary relations in certain fields of research.