Innovation and sustainability in print-on-paper:
A comparison of nanoparticle and deinking niches as emergent sociotechnical networks

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Abstract

Nanoparticle innovation with application to 'print-on-paper' is analysed as an emergent network using social network mapping methods. Its relationship with the innovation network concerned with deinkability for enhanced fibre recycling is explored. Three types of nano-innovations are identified: ink, fibre and coatings applications embedded in heterogeneous networks of nanoparticles and deinkability. It is shown that, in spite of expectations for the potential contribution of nanoparticle technology to deinkability, the networks are actually poorly linked. The primary role of the nanoparticle innovations identified is for commercial printability rather than sustainable deinkability. These findings suggest that broad claims for the contribution of nanotechnology to sustainability are not necessarily translated into specific innovation priorities in business practice. If such potential is to be realised then these currently separate networks need to be linked much more effectively. Key gatekeepers are identified who could potentially contribute to the achievement of this.

Keywords: Nanotechnology; Innovation; Sustainability; Dematerialisation; Paper recycling industry

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Nanoparticles, sustainability and sociotechnical networks

Results are reported from a research project [1] which addresses the prospective role of generic 'info-', 'bio-' and 'nano-' technologies in improving the environmental sustainability of print-on-paper based communication. The context for the study is the argument that incremental improvement of existing technology is not enough to achieve sustainable development, and that radical innovation in technological product and systems is needed. [5]. Radical innovation for sustainability is often framed in terms of new generic technologies, particularly the three emergent '5th wave' domains of technology identified in numerous national and international studies – information and communication technology, biotechnology and nanotechnology [16]. These emerging technologies have formed the basis for some optimistic scenarios for a transition to environmental sustainability. One school of ecomodernisers emphasises the sustainability potential of revolutionary changes in technology with an upstream producer focus. These are considered to offer great scope for major gains in eco-efficiency and dematerialization. The sociologist Josef Huber sees the emergence of 'a new generation of innovative technologies that fulfil ecological criteria'. Examples that he cites include 'transgenic biochemistry' and 'nanotechnology' [17].

Nanotechnology has certainly been promoted in high-level industrial policy and business strategy initiatives as potentially offering radical solutions to the goals of environmental sustainability. Within the EU research and innovation policies, nanotechnology is the third thematic priority area in the Commission's Sixth Framework Programme (FP6) for European research and development projects in science, technology and engineering [18]. The European Commissioner for Science & Research, Janez Potočnik in June 2003 argued:

"Nanotechnology is an area which has highly promising prospects for turning fundamental research into successful innovations. Not only to boost the *competitiveness* of our industry but also to create new products that will make positive changes in the lives of our citizens, be it in medicine, *environment*, electronics or any other field" [19].

In the UK, the Department of Trade and Industry (DTI) Science and Innovation Strategy (2001) includes innovation priorities to support the development of new technology for growth industries of the future. Nanotechnology is included as one of the basic technologies, which will form new industries of the future. In a lot of cases, nanotechnology is often claimed to be a highly promising area that could bring dramatic changes to our daily lives. There is a wide interest in environmental risk and regulatory aspects of nanotechnology, in using nanoparticles in protection and remediation, sensor network, health systems and bio and chemical sensors worldwide.

Nevertheless nanotechnology is also open to diverse interpretation by its advocates and opponents over its feasibility, contribution to sustainability, and its potential risks. A recent study suggested that nanotechnology was in a stage of embryonic innovation and 'path creation' which meant that it was difficult to as yet to judge its contribution to sustainability [20].The merits of advocacy of the contribution to sustainability of nanotechnology innovations are therefore very difficult to judge in general and need to be assessed in relation to particular technological paths. This study explores it in the situated context of nanoparticle innovations in print-on-paper.

In spite of concerns regarding resources and biodiversity, global paper production and consumption have continued to increase. The significance of the printing and writing paper sector is shown by its world annual production measures. The world production of printing and writing paper is about 70 million tonnes, which constitutes 31% of world paper production [3]. Comparing to other paper product category such as packaging, newsprint, household sanitary and others, it is the second largest paper product type after packaging paper products. In the UK, 55% of fibres used in UK paper manufacture are recycled, but with a high proportion being used in packaging and a relatively small amount in office paper [3]. According to the Confederation of Paper Industries, the quantity of printings and writing paper production compared to its recovered paper usage is 1,516,000 tonnes and 167,000 tonnes respectively [3]. In other words, only 11 % of printing and writings paper is used to produce high quality recycled paper. This is on a gradual upward trend and paper researchers report that some papermakers are able to produce high-grade printing and writing paper with 100% of recovered paper [4]. An improvement in office paper fibre recycling rate needs to be encouraged to enable lower consumption of virgin fibres.

Changes taking place in the socio-technical system of print-on-paper embrace a wide range of innovations with the potential for contributing to these sustainability goals. A particular focus of importance is to address the rapidly growing problem of deinking and recycling digitally printed paper texts– mainly from inkjet and laser printing. One innovation area is defined in terms of the 'deinkability process' of print-on-paper for recycling & recovery and draws on a range of new and old technologies in the pursuit of this goal. Another innovation area is defined in terms of the application of 'nanoparticle technology' to print-on-paper. The suggestion is that nanoparticle technology applied to paper coatings and printing inks offers the prospect of greater control over the adhesion and sorption of print on paper. This could potentially facilitate deinking and recycling, particularly of digitally printed (laser & inkjet) paper. We report on developments in these two areas of 'process' and 'technology' and their interaction.

The framework adopted brings together the fields of sociotechnical transitions and innovation networks. The sociotechnical transition approach argues for analysis at a system level defined by the performance of a particular societal function [2]. The transitions approach defines a prevailing 'regime' as the currently dominant social & technological arrangements for the fulfilment of a societal function and explores the dynamics and paths by which such a regime may radically change. One of the key sources of novelty upon which such a transition may draw are 'niches' which express emergent sociotechnical alternatives to the prevailing regime. Radical innovation is often suggested as being generated in niches [6], [7] [8]. However, transition paths may vary as to the degree of resistance, reconfiguration or replacement involved in the encounter between regime and niche. The sociotechnical regime in our study is defined as the '*print-on-paper'* system, which fulfils the social function of text/graphic communication through the medium of a machine, arranged ink display on sheet material derived from wood fibre. It involves a diverse set of actors engaged in practices, which range from forestry to desktop printing to waste paper recycling.

The innovation network approach suggests that the successful achievement of innovation may be conceptualised as the creation of an enduring network of actors, which combine new social and technological arrangements. Freeman stresses that technological innovations must be supported by a corresponding evolution of social arrangements and institutional support [9]. Similarly, Hellstrom pointed out that for ecoinnovation to succeed, innovators must build on relevant social structures and innovations [10]. This uses the idea of network not simply as a distinct mode of governance or policy instrument but as a fundamental conceptualisation of the process of innovation itself... [11]. Innovation can be analysed as a process of construction of a heterogeneous sociotechnical network by enrolment of diverse actors through boundary spanning and communicative interaction.

The significance of an innovation arises from the stabilisation and durability of this network [12].

There is increasing recognition of the fundamental importance of the process of social interaction through networks in the accomplishment of innovation. This foregrounds sociological explanations of technological innovation in contrast to the prevailing economic approaches, whether neoclassical or evolutionary. This sociological orientation has drawn to a significant extent on social network theory and made its initial impact in the 1960s & 1970s. The diffusion studies of Rogers (1971) highlighted the nature of communication networks in the interorganisational spread of innovations and the explanatory and practical value of the concept of homophilous and heterophilous networks and the distinct yet complementary contribution of strong and weak ties [13]. More recently studies have explored the situatedness of innovation discourses within social networks [12] and the role of users in the constitution of innovative networks of practice [15]. This sociological tradition within innovation studies offers a fruitful framework for the analysis of innovative practices involved in reconfiguration of the network of business and other organisational actors involve in this process. Here innovation is considered as a dynamic process formed through heterogeneous network of human actors, knowledge and artefacts, constantly reconfigured through changing political, economic, social organisational and technical relations. Innovations can be identified as socio-technical complexes comprising social actors and technologies, which may change over time.

Our research addresses the meso- and micro-level process of innovation within the 'print-on-paper' sociotechnical system. Social network analysis offers a theoretical and empirical approach to the investigation of the pattern of interactions in a network and whether they are likely to be conducive to the longer term success of an innovation. Innovation is conceptualised as involving the formation of a network of actors. The construction and durability of such a network influences the likely significance and success of the innovation. The success or failure of an innovation network is judged in relation to an existing 'socio-technical system', which is made up of the diverse range of players involved in producing and using, in this case, print-on-paper, such as academics, businesses, industry associations and governmental organisations. The method developed, drawing on social network analysis, is to identify and map emergent innovation networks relevant to deinkability & nanoparticles in order to evaluate whether their sustainability potential is being realised and what might help or hinder this innovative process. The research explores the dynamics of new generic technology based innovations in relation to the sustainability of the 'print-on-paper' socio-technical regime at the meso level, which involves a diverse range of actors, academics, businesses, consultants, governments and industry associations.

One of the limitations of many of the empirical studies on sociotechnical transitions is that they are retrospective in nature and primarily concern economic competitiveness in markets. The regime shift is identified after the event and, with the benefit of hindsight; its sources may be traced to niches where the novelty first arose. On the other hand, prospective analysis including the purposive societal pursuit of sustainability raises a number of fundamental challenges. The nature of a future regime shift will not be known for possibly some decades and the longer-term significance of current niches is highly uncertain. One response to this problem is to emphasise the contingent and inherently unknowable aspects of innovation as an argument for a precautionary approach and the avoidance of misguided attempts to positively shape the future. An alternative, which is what we propose, is to draw upon knowledge about innovation networks in order to map niches as emergent networks with the aim of identifying features, which appear conducive or inimical to their contribution to a transition toward a more sustainable socio-technical regime. It does not seek to assess their fate in the longer-term future. However, in order to pursue this analysis it is necessary to identify specific areas of innovation within generic nanotechnology, which are engaged in downstream commercialisation in order to move on from an over general and abstract bipolar speculative debate about the merits and drawbacks of nanotechnology in general.

1 Mapping niches as emergent networks

The initial phase of the research involved the identification of advocates who promoted innovations with claims for a radical improvement of the sustainability of the print-on-paper regime. These were identified through a web based non-obtrusive approach. Through the analysis of advocacy narratives a number of innovation niches were identified and selected for more detailed investigation. We chose to investigate the two niches of deinkability and nanoparticles in the 'print-on-paper' regime. The particular challenge of such niches is that they are new and near market. Literature based methods applied to the past or to academic science is inappropriate to this task. Instead the web offers new possibilities for systematic capture of more ephemeral and contemporary traces of relevant activity through an 'event based method' [21].

An event base method is used to trace emergent innovation networks in these niches of deinkability and nanoparticles. The type of event sought was a 'knowledge interaction' event with an online 'record' of proceedings. All events selected were international workshops/ conferences with a significant number of presentations on the innovations of interest. A set of events were identified for each innovation niche. The approach has some similarities with the event based approach of Van de Ven [22] which observes, records and analyses the events of the innovation process in different organisational settings. We studied several events performed over a period of 5 years based on the innovation journey described by Van de Ven that " consists of an accretion of numerous events performed by many people over an extended time"[22, p.10]. However the events that we analysed were not specific to a particular organisational context but instead represented a distributed innovation system. Although Van de Ven's innovation journey (1999) [22] indicates the importance of engaging in relationships with others to change institutional and organisational contexts to achieve desired outcomes, the analytical techniques that he and his colleagues employed do not draw rigorously upon network sociology. In our study the events provided the empirical foundation for a social network analysis to reveal patterns of interactive relationships between organisations. A list of organisational actors was derived from these events based on the organisational affiliation of individuals who presented at the event. These were defined as the actors constituting an emergent innovation network.

Theoretically our focus on innovation networks draws on perspectives from within the sociology of technology. Actor network theory (ANT) is the core concept associated with the work of Callon [23], [24], [25], [26], [27], Law [28], Latour [29], [30], [31] and Akrich [32], [33]. It emerges from the study of both the production of scientific knowledge and the study of technological development, and is a core approach in the social study of technology. Callon [24, p.83] points to the particular orientation of ANT, concerned with the "steps from the birth of an idea (invention) to its commercialisation (innovation)", achieved through description of the links between human and non-human elements, thus people, organisations and artifacts are constructed into an interacting system which changes over time. Thus, ANT uses the principle of symmetry to overcome the boundary between the social and natural world, and to explain the gradual progression of a new technology to "describe given heterogeneous associations in a dynamic way and to follow, too, the passage from one configuration to another' Callon (1987: 100) [24, p.100]. The concepts of ANT include the process of negotiation and enrolment that actors go through to join the network. The dynamics of change are constructed through "obligatory points of passage", resulting in a construction of the socio-technical network which is both stable and robust, while Callon uses the concept of 'translation' to explain the dynamic process of the network.

The network relationships between the actors in our empirical study are measured and defined in terms of copresence at events and coauthorship of presentations. A link represents knowledge flow and social interaction between actors. A co-presence network link between 2 actors was deemed to exist if they were presenters at the same event. A further co-author network link was allocated if two actors jointly authored a conference presentation. The two sets of relational data were created in Excel as an affiliation-by-affiliation matrix. The configuration of the emergent innovation networks was explored using the visual mapping software, NetDraw. The merits of visual mapping of innovation networks are that they allow a variety of relational and attribute data to be combined enabling a mix of quantitative/qualitative and micro/macro analysis. The Excel matrix file was imported into the social network analysis software, Ucinet, and transformed into Ucinet dual-file format. These Ucinet relational data files were used in NetDraw to enable the network to be visually mapped.

The primary purposes of the network mapping were: to show the overall network configuration through a spring embedding graph-theoretic layout; to identify clusters within the network through faction analysis; to assess the homogeneity/heterogeneity within and between these clusters using nodal multiple attribute data; and to identify actors who occupied gatekeeper positions in the network by the use of a betweenness centrality measure.

Gatekeepers are significant in terms of influencing technological change and contribute to the success of innovation. Work by Allen and Cohen [34], Tushman [35] drew early attention to the importance of boundary spanning and the role of gatekeepers and other network intermediaries in the management of innovation at the organisational level. Tushman and Katz [36] found gatekeepers tend to be high performers and they are key to facilitate information transfer. Previous research by Conway [37]; Kreiner and Schultz [38]; Allen [39] has consistently found that interpersonal communication rather than technical reports, publications, or other written communications are the primary means that innovators collect and transfer ideas.
Attribute data was assigned to actors in terms of type of organisation that they belong to (node shape), country of origin (label), number of individual innovation actors from the same organisation (node size) and their technology focus (node colour). Similar to concepts investigated in Van der Ven's innovation's journey [22] the analysis addressed ideas and outcomes (technology focus), people (organisation members), relationships (collaborative links) and context (type of organisation national location). A diverse range of external actors including research organisations, suppliers, competitors, users, consumers and distributors play an important role in the innovation process (Shaw [40]; von Hippel [41]; Vanderwerf [42]; Schrader [43]; Conway and Steward [11]) and are important external sources in contributing to innovation success Myers and Marquis [44]; Achilladelis *et* al. [45]; Langrish *et* al. [46]; Gibbons and Johnson [47]; Conway [37]).

The attribute file was created in relation to the matrix file in Excel and imported to Ucinet in order for Netdraw to incorporate it into the network diagram. The two innovation networks were mapped and analysed separately and were then combined together. Interpretation of the network was made using an enhanced and combined network map.

A further event analysis was undertaken to identify innovations in the nanoparticles and deinkability areas. It was ensured that all innovation actors were included on the network map and were added as isolates if not present in the network based on the knowledge interaction event analysis. These events were *'innovation occurrence'* events, which were identified through an online search for reports of these events published in a comprehensive pirabase paper industry database and US/European patent database. The innovators are plotted in fig.1.

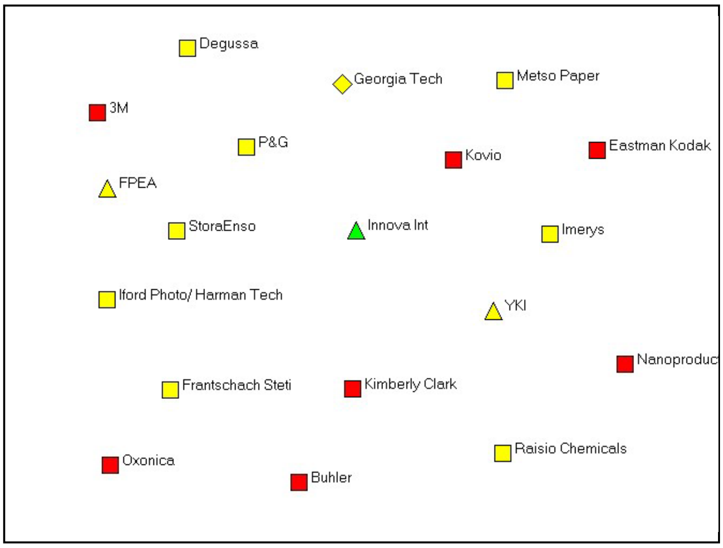


Fig. 1. Pirabase and patent innovators in isolated network

2 The deinkability innovation network

Ironically it has been the impact of the generic technology of information technology that has contributed to the problem of deinkability of cut sheet office papers. Smyth reported that there is a widespread growth in low-cost A4 inkjet and laser colour printers for printing pages in UK as well as in Europe. Companies are printing their business documents internally rather than outsourced to commercial printers [48]. Significant increases in relative shares of digital printing by non-impact-printing methods such as photocopies, laser printers and inkjet in businesses and home offices is expected in the next 5 years. The first two depend on toners, dry fine powder (with pigments) which bond the paper fibres together. These cause particles that do not float or sink in paper recycling processes causing 'speckling' of final paper products. With water–based ink–jet inks, dyes dissolve and attach to the paper fibres during the recycling process, causing discolouration of the final paper [49].

The growth of inkjet printing has been based on the small and home office market (SOHO), which is still growing at 20-30% (with 170 million printers sold over 20 years) [4]. This growth poses a potential problem to the recycling business, as ink jet inks contain water-based dyes that are not easily removed by current de-inking techniques of washing and flotation and tend to discolour the final recovered paper product. Printing inks are liquid suspensions of variable viscosity depending on the printing process. De inking difficulties are posed by the presence of soluble pigments or dyes, which cannot be removed by washing or floatation. This is comprised of a blend of oligomers and polymers in one of several solvents or dilutants. Three categories of chemical are involved, the pigment or dye, the vehicle and additives. The vehicle importance is that it determines the ink drying mechanism and ease of deinkability [50]. The vehicle has two major roles, transport and binding of the ink on the substrate and after ink drying the vehicle forms a continuous film at the surface of the substrate. If the solvent is water, as it is in inkjet ink, the pigment is soluble during re-pulping [50]. In the case of additives such as waxes and drying catalysts, these are used in small proportions to enhance ink properties. In general, the chemical composition of ink is designed to maximise the properties and appearance of the final print, rather than to facilitate de-inking during recycling. This implies there may be a conflict between printing and de inking characteristics [50].

2.1 The deinkability network

The overall network includes 48 different organisations. The network mainly comprises business organisations from a range of European countries and the US. There is an even spread of technological specialisation in inks, fibres and general processes with no apparent activity on paper coatings. There is low representation of academic research organisations and public bodies in the network.

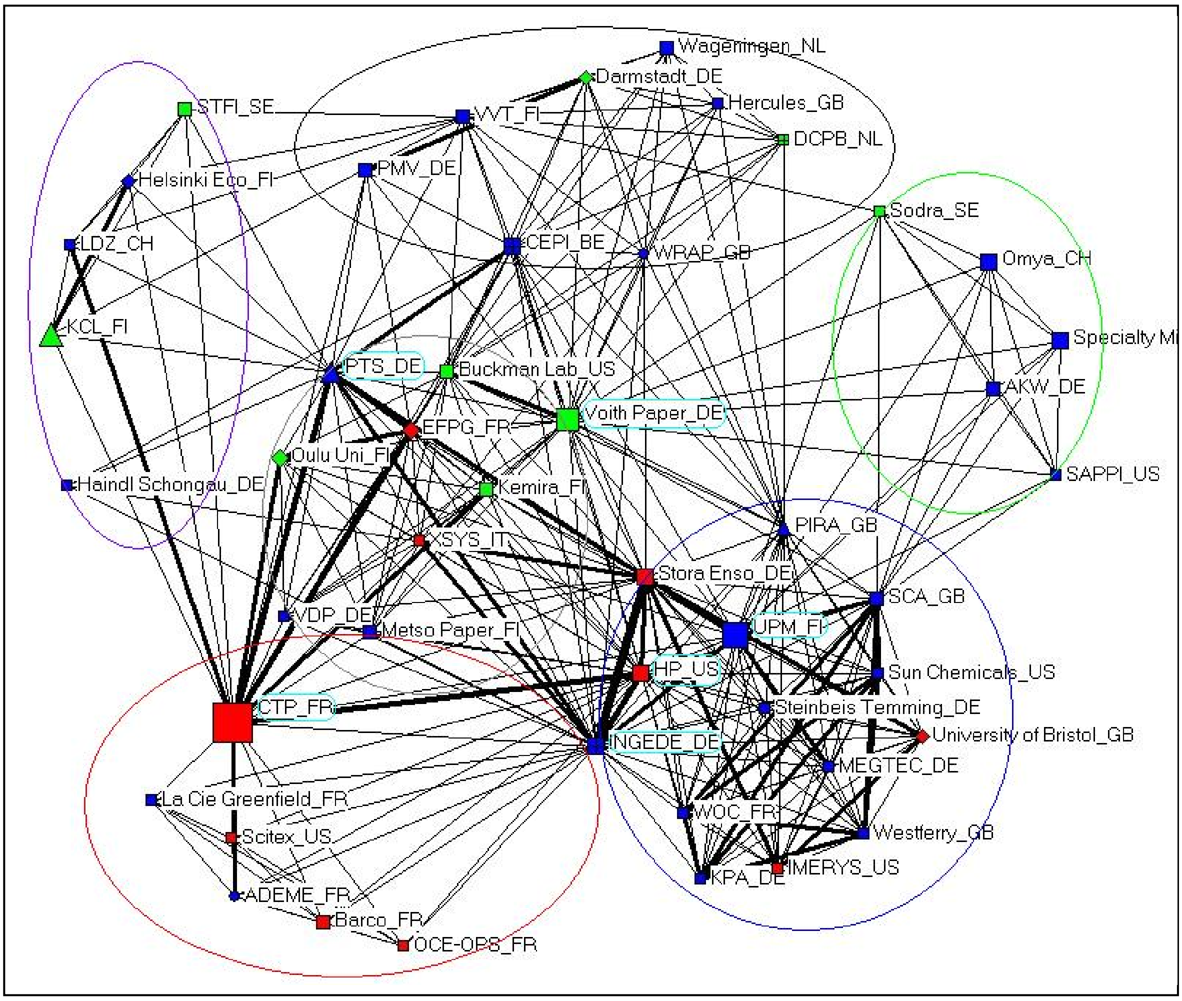
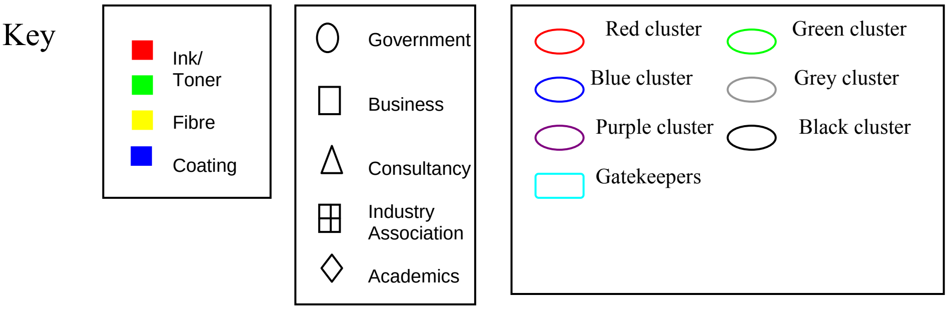


Fig. 2. Deinkability network map.



2.2 Clusters in the deinkability network

The analysis shows that the clusters are mostly heterogeneous in nature, mainly business-oriented and separate into 6 different clusters. Grey, red and blue clusters have a technological focus on ink. Among them, the red cluster is a homogeneous cluster of French organisations mostly working on ink/toner technology. The second largest group (grey) also shows some technological variety with a mixture of interests in ink and fibre. The remaining clusters are smaller, though they all show international diversity combined with a narrower technology focus. Organisations in the grey central cluster, largely business oriented, reach less than half of the organisations in the blue cluster (See Fig. 2). There is only one organisation in grey cluster, The Paper Technology Specialists, Germany (PTS_DE), a German consultancy which can reach the actors in the purple cluster. This organisation is a research and consultancy firm founded by the 3 German research and industrial organisations. It focuses mainly on chemical management of paper (e.g. starch, fixation, retention, sizing etc); fibre technology (e.g. flotation, refining, fractionation, washing, bleaching etc.); surface technology (e.g. optimising raw materials use through binders, additives, nanotechnology and barrier materials). It partners with INGEDE on a number of projects from 2002 to 2006. Half of the organisations in this cluster concentrate on fibre engineering. One-quarter of organisations focus on ink/toner technology.

All of the organisations in the black cluster have links with the organisations in grey and blue clusters. The VVT Technical Research Centre, Finland (VVT_FI) and Confederation of European Paper Industry, Belgium (CEPI_BE) are important communicators between the black and purple cluster. Papierfabrikation und Mechanische Verfahrenstechnik, Germany (PMV_DE) and Confederation of European Paper Industry, Belgium (CEPI_BE) link the red and black cluster. VVT Technical Research Centre, Finland (VVT_FI) is the only connector between black and green cluster. Voith Paper, Germany is an important actor in linking the grey central cluster to the 5 organisations in the green peripheral cluster, which other organisations in the cluster cannot reach. It is desirable for Voith Paper to share its knowledge in recycling process as it claims that it has developed innovative recycling processes in which impurities in office waste paper, such as various kinds of printing ink, coatings, unbleached and colored papers, stickies, fillers and contaminants of all kinds, are removed reliably or rendered harmless. The secondary fiber stock produced can replace virgin pulp in the production of high-grade writing and printing papers, thanks to its outstanding optical and mechanical properties. Referring to the purple cluster, Haindl Schingau is an important actor in connecting the blue cluster. The organisations in the black and grey clusters connect fully to the purple cluster. Over 30% of the links are connected to black and grey clusters. The purple cluster does not connect with the green, which can form a barrier in knowledge transfer. The grey cluster is least connected with the purple cluster where more connections can be beneficial in developing fibre engineering.

2.3 Gatekeepers in the deinkability network

Most of the significant gatekeepers are business organisations in the paper, printing and deinking sectors. 2 international consultancies, 2 global manufacturers and 1 industrial association also appear in this role. The top 5 potential gatekeepers that have the largest number of connections with other organisations are: INGEDE (119.31), Voith Paper (119.237), Centre Technique du Papier - The Pulp and Paper Research & Technical Centre (CTP) (114.44), UPM-Kymmene (110.373) and HP (103.417). Most gatekeepers connect to grey and black clusters, they are less connected to purple and green clusters. In particular, both INGEDE and Voith Paper connect 4 out of 5 different clusters, which shows that they are the most active in linking diverse innovation activities.

2.4 Innovation activities in the deinkability network

Five cases of collaborations are found with different organisations mainly in the central position in the network, and some sustainability objectives are found. The business practitioners, include Web Offset Champions Group (France), Sun Chemicals (UK), SCA (UK) and West Ferry Printers (UK) and are openly discussing leaner, faster and more efficient runnability issues. The business research institutes, Centre of Technique du Papier (CTP) and Kemira concentrate on the best surfactant strategy in relation to deinking. 3 remaining types of academic, business organisations or industrial organisation are found. University of Oulu, Centre of Technique du Papier (CTP) and the engineering school of National Polytechnic Institute of Grenoble (EFPG) which concentrate on deinking processes: cleaning, screening and flotation. The Finnish organisations, KCL and Helsinki School of Economics collaborate to seek appropriate sustainability indicators for new technologies.

The success of de inking depends on ink properties and printing techniques and conditions, along with the age of the print and paper surface. High grades of top quality waste paper which require little or no cleaning, such as unprinted trimming off cuts and scraps from the manufacture of office paper are ideal for recycling. Deinking grades, where the ink must be removed before the recycling process present more challenges. From the industry perspective, deinking is seen as a sophisticated way of recycling, and high-grade papers can be recovered by using this techniques [51]. The main deinking processes involve the removal of ink and other contaminants by screening, cleansing, flotation and washing from sorted and recovered paper (waste paper). The European Council of the Paint, Printing Ink and Artists' Colours Industry estimated that there is growth rate of 20% per year in the quantity of office paper printed by "non-impact methods" based printing technologies such as photocopiers, laser printers and ink jet printers [50]. Although this type of printing method uses a low level of additives based on pigments in dry toner, they strongly bond to a large number of fibres and they do not float or sink and are retained in the deinked pulp in the paper recovering process. They are often described as poor deinkability. There are also industry moves to replace solvent based inks with more environmentally friendly water based pigment based inks to reduce VOC emissions. The main drawback is that papers printed by water based ink jet inks pose another problem for deinked pulp. Dye redissolves, is unable to separate out and subsequently move to the fibres which make it difficult to produce high quality paper. From the deinkers' point of view, it would be desirable to contain as few chemicals as possible in order to reduce contamination of the deinked pulp and therefore increase the possibility of producing high quality brightness of office paper. But from the papermakers' point of view, Baker explained that the optimisation of additive and sizing agents to paper is both a cost reduction and paper quality one as minerals such as china clay, chalk and titanium dioxide will improve sheet formation, surface smoothness, printability, dimensional stability, opacity and brightness [52]. One of the complexities of recycling in the high quality printing and writing paper industry is that it involves with a wide diversity of actors with their individual conflicting objectives in the paper chain, from ink manufacturers, publishing and printing companies, waste collection and sorting companies, consumers and recycled paper mills.

The quality of recovered high grade writing and printing papers depends on the co – operation of organisations that manufacture and use paper to maximise its potential for recycling. These organisations include paper manufactures, publishers, ink and coating manufacturers, as well as machinery developers. In particular, ink developers should be encouraged to consider the effects on the de inking process. Recovered paper process treatment may give variable results due to the recovered paper quality, printing processes and ink content, age of paper and climate, all can influence the final result, so the increasing challenge for pulp de inking is to maintain standards both of yield and quality as paper collection gets increasingly mixed and the amount of virgin fibre in recovered paper decreases with an increase in recycling. Recovered paper is a delicate business which can be affected by decisions on printing and publishing: "To maintain the achieved standards, it is also necessary that everyone involved in the paper chain – including parties giving the order and design of print products – give due consideration to the requirements of recycling" [49]. This requires an understanding of the life cycle implications of such products. Paper fibres are only suitable for recycling between 5 and 10 times before they start to disintegrate and become unusable. Recycled pulp differs from fresh pulp in a number of ways, such as the age of the fibre, ash content, the mix of fibres content and origin and its bonding ability. Also it contains various contaminants including, chemical additives from the original paper production and the de inking process. Caree and Magnin report on a de-inking experiment carried out on coloured ink printed by seven different ink jet printers. They found a wide diversity of successful de inking, commenting that 'dialogue is necessary with ink jet ink manufacturers' to promote the use of inks which are most successfully removed at the recycling phase [4]. Also, most studies of de-inking toner prints have been carried out in North America, showing high contamination of residual black impurities.

The demand from customers regarding paper environmental impacts can also act as a driving force for change, and there is a growing interest of customers in viewing the actual performance of paper mills [53]. At the same time, there is customer demand for brighter paper which requires higher grade input and in many cases a greater proportion of virgin fibres pulp. Ulrich Hoke, the Chairman of INGEDE, comments that the problem of increased recycling is that the quality of recovered paper gets worse and both digital and flexo prints make more difficult the recovering and deinking process. Future challenges lie in recovering a greater percentage of higher quality paper, avoiding non-deinkable paper preventing non-removable adhesive applications [54].

One issue is to maintain a high quality product from the deinking process to compete with products from virgin fibre. Also there are pressures to reduce pulp-processing costs while increasing yield and production capacity. Adopting new processing technology can improve ink removal while improving fibre recovery (for example dealing with the summer effect when heat dries out the oils in ink making them difficult to remove). The process of deinking involves the tasks of separation of the non-paper components, and removal of the printing ink film from the paper fibres. With coated paper the ink does not touch the paper fibres, the coating disintegrates and the recovered paper is pulped. With uncoated paper there is adhesion of the printing ink to the paper fibres and ink removal is dependant on paper properties, like surface structure, fibre type, ash content as well as drying mechanism of the printing process. Removal of the ink and any other material (such as stickies) is carried out (commonly in Europe) by floatation. Currently, measures for the general assessment of paper recyclability are being developed by European Institutes and paper mills.

An associate professor of North Carolina State University reveals the process complexities of deinking printing and writing paper and the barriers to investment in a recycling facility for this type of high quality paper. He emphasises that deinking practice can profoundly alter the proportion of fibres and fine materials in the recovered material; substantial fibre loss can result from the deinking process. Laser printed sheets or copies rely on xerographic process of forming an image on paper do not disintegrate well when the wastepaper is re-pulped in the first step of recycling. And this type of high-tech deinking mills is discouraged by the high capital and operating cost of the recycling process [55]: needing a diversity of approaches "E-publishing, regulation of printing ink compositions, incineration of contaminated paper to recover its energy value, producing paper from renewable resources and continuing subsides for paper recycling programs;" to "help sustain the marginally economic advantages of de-inking operations" [56].

A German professor and chair of Paper Technology and Mechanical Process Engineering at Darmstadt University of Technology places much emphasis on the operational difficulties such as poor deinkability of different types of printing and writing papers such as woodfree copy paper, commercial inkjet paper and woodcontaining recycling paper by. His expectation is on developing better deinkable ink jet ink systems and collective efforts from all parties (e.g. designers of printed products). He recommended that designers of printed products should give consideration to the requirements of recycling [57]. The French senior research scientist, from the Recycled Fibres Group of the Centre of Technique du Papier (CTP) has concentrated on printing technologies and their effects on deinking since 1999. He has concluded that oil-based inkjet inks on coated paper and dry toner are the preferred technologies compared to other various digital prints consists of dye and pigment based inkjet, normal toners (high speed black and white and colour, liquid and dry) and UV curable technologies (overcoats, ink and toner). He does not consider which new technologies could possibly bring to make deinking easier.

The Managing Director from the International Association of the Deinking Industry (INGEDE) believes that "more recovered paper can and should be recycled…for higher quality graphic papers recovered paper can be used as a resource. In order to keep these products light, to avoid them getting darker even going through multiple recycling, the ink has to be removed…through a deinking process. This process should harm the environment as little as possible, and it should also lead to a high quality product. To achieve these goals, everybody involved in these steps has to cooperate". INGEDE therefore cooperates with other players in the field of recycling, as with printing ink and machinery manufacturers, paper finishing industry and suppliers of additives. The current members are 37 paper mills and research departments of paper mills from Austria, Belgium, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the Czech Republic and the UK. The workshop "Deinking of Digital Printing Inks" addressed the growing importance of digital printing processes by photocopiers, laser prints and inkjet prints. It was pointed out that "the manufacturers hardly think about the fact that the print products created by these processes contribute to the waste paper collection by the users. Almost all of these products harm the paper recycling process rather than contributing to the recovery of valuable resources - they ought not to get into recovered graphic paper, because the ink systems that are being used can be removed either poorly or not at all. Most companies did not realize the importance of this kind of discussion. Recyclability did not improve or got even worse for some quality parameters" [58]. Current research by Carre and Magnin on the various deinkability behaviours of digital prints discovered that not only are waterbased ink jet inks not deinkable, but 10% of them in the mixture deteriorates the deinking of the whole mixture [4]. Deinkability criteria should be integrated when designing new inks especially in the area of ink-jet printers to avoid more environmental friendly water-based ink disrupting the paper recycling process

Faul (2005) suggests that sustainability in recycling printed-paper products could be difficult to achieve at present. He acknowledges the importance of paper recovery, but expresses concern on the type of inks and kind of printing process could lead to difficulties in the deinking process [24]. He added that for printed-paper products to be recyclable, they have to be repulpable, adhesive applications must be removable by screening and cleaning and deinkable. In particular, the deinking process consisting of flotation and washing could lose up to 55% of fibres. The Royal Society of Chemistry's chemical science network stressed that the problem of deinking is not new, recyclers had experienced the difficulties in deinking from the recycled wastepaper in the past. Removing ink components or toner materials from high quality laser paper made from virgin pulp is a challenge to most recyclers. Until late 1994, a complex super deinking process is found to remove various inks found in mixed office waste in order to produce high quality office paper. The problem of recycled pulp is that it results in poor mechanical fibre properties and must be mixed with 70 to 90 percent of virgin pulp to produce high-quality paper. Faul (2005) stresses the importance of solving deinking problem, "for the sustainability of the paper loop a sufficient deinkability is necessary" [59]. He also emphasises the need to include recyclability as a criterion from the design stage of the product life cycle in the near future. "When designing a print product, a good recyclability should be considered". He highlights the urgent need to tackle technical problems of deinking to pursue sustainability [59].

3 The nanoparticle innovation network

The potential applications of nano-technological innovations to deinkability fall into 3 major areas: nanocoatings, nano inks and nano fibres. The global chemicals, inks, paper, printing and machinery manufacturers all play a role in shaping the future of deinking technologies

(i) *Nanocoatings*

Compared to other nanoparticles applications, nanocoating is well established and near the market. Growing silica monomers into clusters (nanoparticle technology) in wet end chemistry has been used by papermakers since the 1980s to improve retention and drainage systems. This composition improves formation, retention, drainage and dry strength of paper. Since then, it has continued to make continual improvements in terms of combining structured nanoparticles with colloidal silica sols and synthetic cationic polyacrylamide (C-PAM) that has resulted in cleaner fine paper. Silica spheres form strong covalent siloxane bonds that cannot be easily broken by paper machinery. Nanoparticle application in papermaking is results in reduced steam production as well as paper with higher brightness (Hanninen, 2004). In 2000, a Compozo Select system combines with anionic trash catchers (ATC), cationic starch, C-

PAM and further additional nanoparticles was applied in a closed recycled paper system. It is claimed that it is favourable to apply to a system involving broken/ poor quality secondary fibres, control soluble and redispersible components (stickies residues) at all levels of water closure. New nano coating and converting techniques in recent years are claimed to bring dematerialisation in terms of decreasing the amount of filler and coating required and solve part of the recycling problem by replacing the difficult-to-recycle coatings.

(ii) *Nano inks*

Recent developments in nanotechnology are beginning to offer novel opportunities and are increasingly being considered by ink manufacturers and customers, to enable inks to be developed with superior performance properties. Nanoparticles are also used in colloids, which in turn find application in printer inks. Inkjet inks are another area where nanoparticle technology is being utilised. In 2005, Oxonica (European Nanomaterial company) and Buhler Partec (a process technology manufacturer for making printing inks, pigments and chemicals) announced their nano inks research concerning the replacement of the conventional colourants with nanoparticle dyes and nano-sized pigment particles. They claimed that the newly developed nanoparticle dyes will never fade and produce a high-quality image. Global chemical manufacturer and supplier, BASF is also working on making nanomaterials to provide colours without the use of dyes or conventional pigments. They claimed that the colours of their nano inks are generated by dispersions of uniformly sized nanoparticles in the same way that colour is created by the ordered, textured surface of butterfly wings. A key question is whether this may help deinkability.

(iii) *Nano fibres*

Ongoing research has been undertaken in the US to develop next generation fibre recovery and utilisation through the use of nanocatalysts to liberate cellulose, hemicellulose and lignin components, separation of wood into fundamental architectural constituents such as microfibrils and nanofibrils and use of nanofibrillar cellulose in building blocks. In Sweden, research has been directed to the use of nanoparticles for surface/ interface modification of pulp fibres and wet end applications in order to achieve high performance retention/ drainage with the addition of nano colloids for tailored surface properties.

13 specific nanoparticle innovations were identified as being at the stage of commercialisation. Of these 11 concerned coatings, the majority of which involved silica nanoparticles. 2 were concerned with nanoparticles applied to ink technology.

3.1 The nanoparticle network

The overall nanoparticles network comprises 65 organisations. The colour of the node represent the type of technology they are focusing on ink/ toner (red), fibre (green), coating (yellow)- - general environmental and risk (blue). The shape of the node represents the type of organisation: government (circle), business (square), consultancy (up triangle), -industrial (box) and -academic (diamond). The size of the node also indicates the number of individuals engaged in knowledge interaction. The larger the size of the node, the larger the number of presenters involve in the events. Business organisations represent the largest number of actors but there are also a reasonable number of academic organisations from US, Canada, Finland & UK. Research interests in inks, fibres and coatings are present.

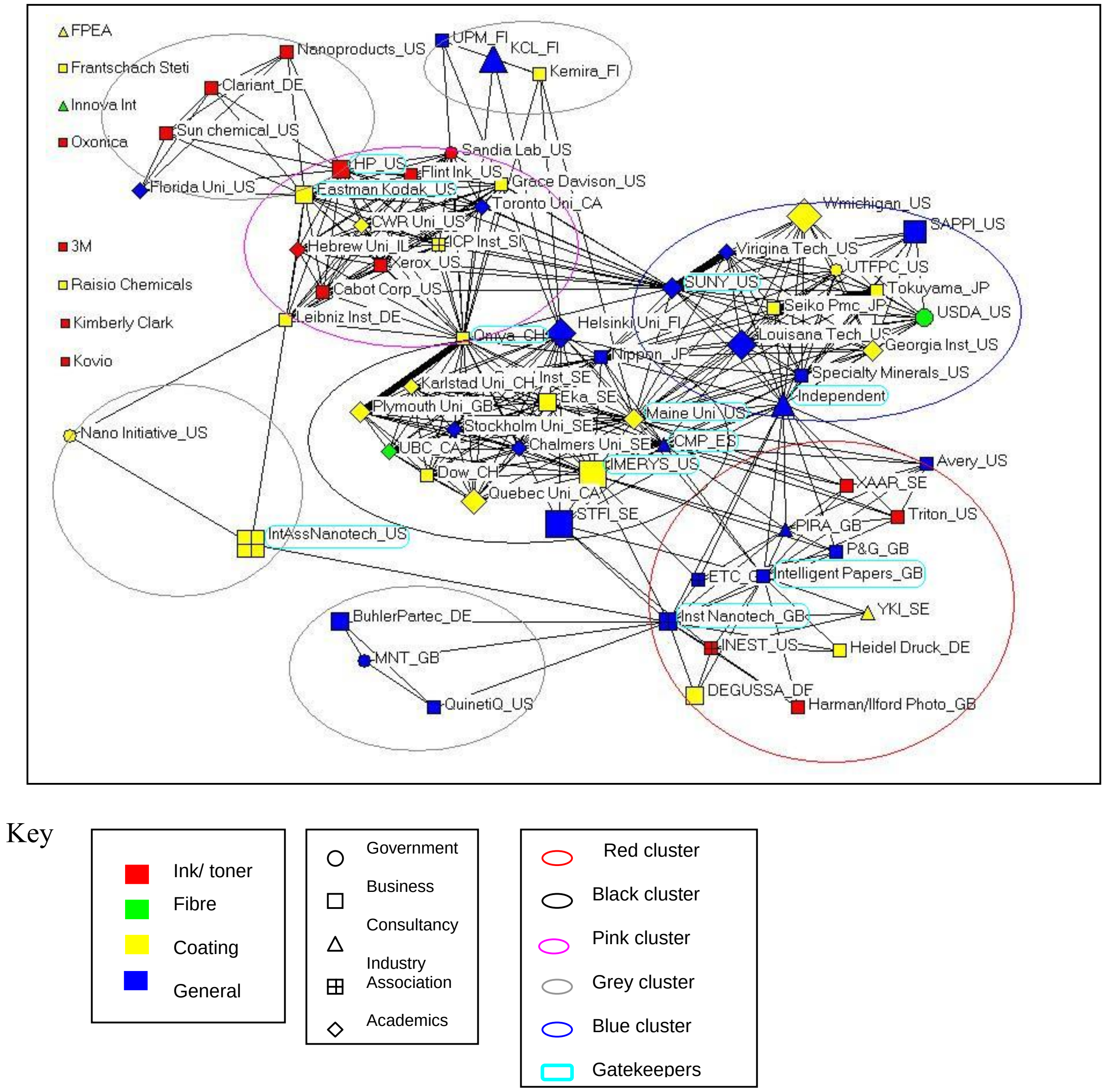


Fig. 3. Nanoparticle innovator network diagram

4.2 Clusters in the nanoparticle network

The network is differentiated into 5 clusters. The centre of the network contains mostly a heterogeneous mix of European, Canadian and US academics. Active knowledge interactions are shown within US academics and businesses whereby 3 or more clusters are dominated by the US organisations. There is a broader organisational interest on the nano application to coating (including 7 academic institutions from Canada, Switzerland, UK and US; 12 business organisations from Japan, Finland, Germany, Sweden; Switzerland and US; 2 industrial organisations from US and Slovenia; 1 US government. and they are distributed across different clusters. In comparison, nano application to fibres has caught less attention compared to ink and coating formulations. The 3 cases of nanoparticle to fibre applications only appear in two clusters (black and blue clusters) located in the centre part of the network (See Figure 6). The 8 organisations which focus on ink/toner nanoparticle technology appear as isolates. Together with the isolates, there is a high degree of homogeneity in ink/toner technology in the pink and grey clusters and most organisations are US oriented firms. They can possibly share the expertise to accelerate the ink/toner technology development with Cabot Corp, Sandia Lab, Flink Ink, Xerox, HP, Sun Chemical and Nanoproducts. The popular choice of nanoparticle applications is coating technology, where the most of the organisations position in the central network map. More knowledge sharing/ collaborations in coatings are favourable among Eka Chemicals, Imerys, Maine University, Omya, Quebec University and Plymouth University.

3.3 Gatekeepers in the nanoparticle network

The gatekeepers represent a mixture of business, academic and consultancy organisations. The top 5 potential gatekeepers that have the largest number of connections with other organisations are: Omya (402.461), Institute of Nanotechnology (304.029), Independent Consultants (224.502), State University of New York (219.736) and Maine University (203.74). Most connections are found to connect purple, blue and red clusters.

3.4 Innovation activities in the nanoparticle network

Advocates of nanoparticle innovations in print-on paper with claims for sustainability are found among consultants, academics and industrial organisations. A Finnish paper consultant, from Jaakko Poyry suggests that nanotechnology can offer practical implementation of the principle of dematerialisation through 3 routes: (1) By reducing the amount of energy and materials required to accomplish a desired task, it can provide goods and services with a smaller environmental footprint and less materials to be recycled. (2) Maintenance and replacement of process equipment can be minimised via stronger materials. (3) Enhanced process control results could result in increased production of recycled fibres with the desired quality. Specifically, she argues that incorporating nanoparticles could make the deinking process more efficient, since nanoparticles have a larger specific surface area their greater reactivity could increase flotation process efficiency [27]. Another Finnish paper consultant, from KCL Science and Consulting suggested that application of nanotechnology could produce new end products with desired properties by controlled barrier/sorption properties, tunable adhesion and other properties with new coating and converting techniques. New controlled barrier/sorption can result in better printability. Tunable adhesion would control the release of substances. New coating and converting techniques could bring dematerialisation in terms of decreasing the amount of coating required and solve part of the recycling problem by replacing the difficult-to-recycle coatings. The visions of the future nanotechnology are in high-value end products, which aim for a big improvement of 30% instead of a 3% [28]. He believes that nanotechnology application could bring factor-10 improvements in the future. Similar to the view of two Finnish consultants, a UK consultant from PIRA International, an UK paper research consultancy holds an optimistic view of this particular technology. He believes that nanotechnology has a lot of potential to sustainability.

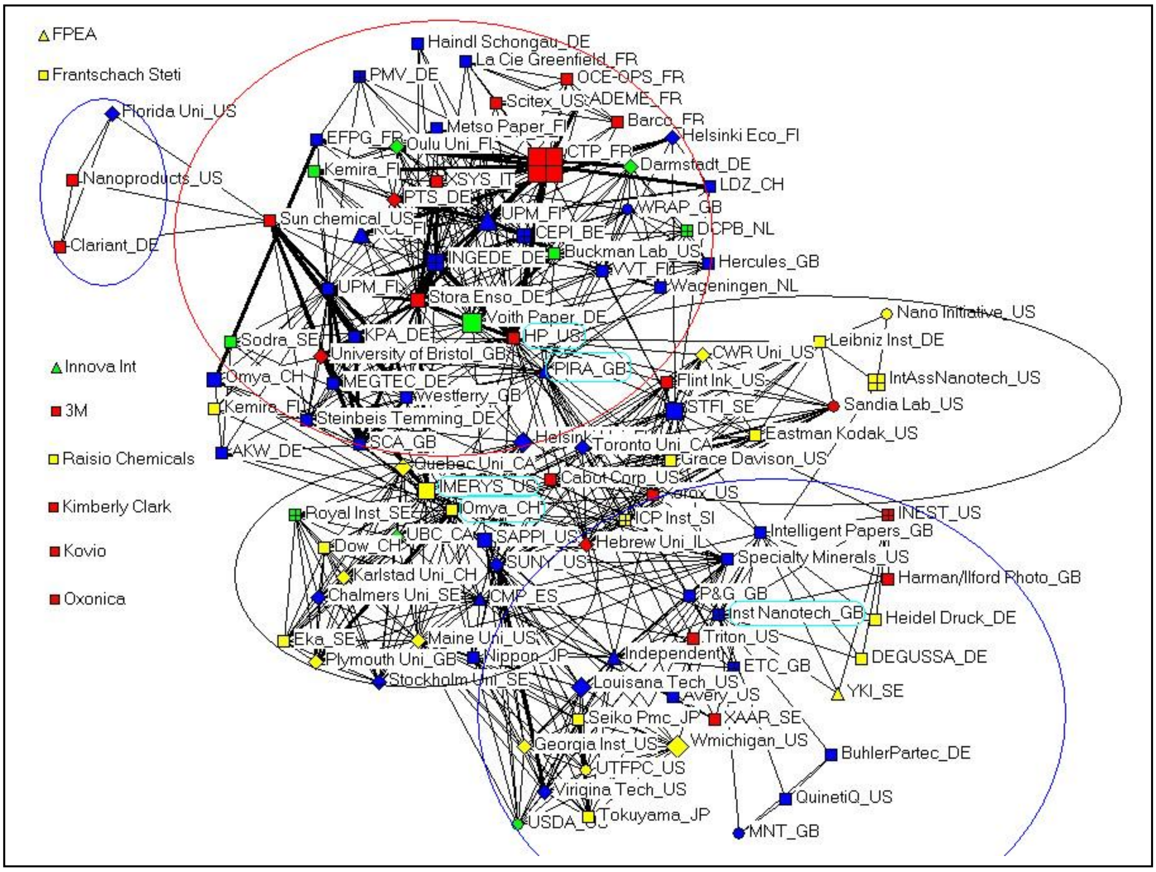
Academic contributors tend to be more cautious. A professor of US Institute of Paper Science and Technology within Georgia Institute of Technology pointed out that nanotechnology has potential to contribute in many areas; it is too early to confirm if nanotechnology can help in the deinking process and thus encourage paper recycling.

“Although nanotechnologies have been widely used in many areas and exciting applications in paper and papermaking have been proposed, it is difficult to give an example for deinking. The possible applications of nanotechnology in deinking may include surface modification of ink particles and fibers using nanostructured particles or molecules; using nanosized inks (easy for washing); nano-air bubble interaction with ink particles have not been studied so it is difficult to say it will be good or bad. In summary, nanotechnology may improve ink removal, but it is too early to say that” [29].

A number of nnovations within the area of nanotechnology in relation to printing and writing paper with relevant applications have been identified. For example, Degussa, a German business has been developing small-scale pigments to work with print heads. While Nano Products, a US business, is using nano-particles in dispersion and inks, for pigment and coating materials. Degussa has products that integrated nanopigments for use with inkjet inks. Kodak, the manufacturer of traditional imaging products has been involved in making polymeric nano-particles comprising simple or complex (entangled) claims of molecules. These can be used to make mordants – substances that help to bind ink dyes to surfaces such as inkjet printer paper. A patented Kodak mordant is used in Kodak inkjet paper. Mordants are made of cationic polymeric nano-particles and other materials, which form a film on coated paper. They claim that nano particulate mordants are very effective because the smaller size particles are more densely packed in a coating. Overall, the claim is that nanotechnology applied to paper coatings and printing inks offers the prospect of greater control over the adhesion and sorption of print on paper and would therefore facilitate deinking and recycling, particularly of digitally printed paper (laser & inkjet). 101 presenters from 65 organisations from nanotechnology and 109 presenters or participants from 48 organisations from the deinking industry and in relation to paper industry are gathered to form two sets of relational data.

4 Interaction between the nanoparticle and deinkability networks

4.1 The nanoparticle-deinkability network



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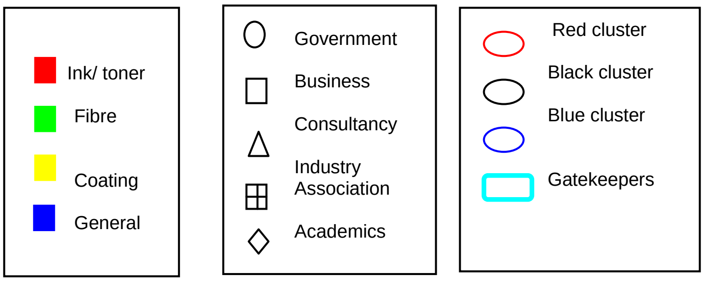

Fig. 4. Combined nanoparticle and deinkability network.

In combining the two separate networks, we found that there is not a great overlap of actors between the two networks. In identifying the gatekeepers, there is scope for them to catalyse other actors into action as well as work together to put forward possible technological partnership to face challenges in the paper recycling industry (See fig. 8.). The 9 organisations that participate in both networks and play an important mediator role in communicating between two innovation networks are all business oriented: HP (digital printing manufacturer), Imerys (chemical and coating manufacturer), KCL Finland (paper consultancy), Pira International (paper consultancy, conference organiser and information provider), Metso Paper (paper equipment and machinery provider), SAPPI (paper manufacturer), Specialty Minerals (paper chemical manufacturer), STFI-Packforsk (paper recycling consultancy) and UPM (paper manufacturer). More radical innovations would require interactions between a wide diversity of players including those significant actors mentioned above in the future.

4.2 Clusters in the nanoparticle-deinkability network

The combined network is not as clearly differentiated as the separate networks. The prominent clusters (black, blue) represent the persistence of the large strong clusters in the nanoparticle network. Essentially it shows a low level of integration of the nanoparticle innovation activities with the deinkability innovation activities.

4.3 Gatekeepers in the nanoparticle-deinkability network

The top 5 potential gatekeepers that have the largest number of connections with other organisations are: Hewlett Packard (HP) (771.77), IMERYS (655.761), Pira International (647.717), Institute of Nanotechnology (582.85) and Omya (518.231). Although there is some continuity with the gatekeepers in the separate networks there are also new actors, which appear to have a greater significance in the combined network. However the connectedness between the principal gatekeepers is low.

5 Conclusion

The research has shown that there is an emergent network of innovation activities on nanoparticles applied to the print-on-paper regime. However this network is so far poorly linked to the emergent network of innovation activities on deinkability (*refer to fig. 4.*). This suggests that the sustainability claims for nanoparticle innovation are not being very effectively fulfilled. This is borne out by the nature of the nanoparticle innovations currently at the stage of commercialisation. They are primarily concerned with traditional commercial performance concerns such as ‘printability’ rather than new sustainability objectives such as ‘deinkability’ for enhanced recycled fibre in print on paper. We have seen some sustainability collaboration examples in dematerialisation. There is evidence that both academics and entrepreneurs (especially global companies) worldwide are making continuous effort in integrating nano particles in order to improve the current material characteristics and invent in new nanomaterials. For example, the use of nanoparticles in replacing conventional dyes will lead to reduction in materials use.

It is confirmed that examples of nanotechnology application to printing and writing paper are limited at present. 3 major areas of the current technological innovations are identified: inks, fibres and coatings. Nanocoatings receive the most interests in the nanoparticle network from business organisations, more research should be carried out in proving that its application can assist deinking process. Coated paper has no contact between ink and fibres, it is less of a problem. For uncoated paper, printing inks stick firmly on the fibre, which is more difficult to remove, and the age of the inks can significantly reduce deinkability. Surprisingly, there is comparatively less collaborative research between research establishments and businesses in both network. Both government and industrial organisations should encourage research to continue, in particular to specific industry.

It is found that both deinkability and nanoparticle networks have some similar characteristics: largely business oriented and mostly comprises of heterogeneous clusters. A key difference in technological focus lies in that the deinkability organisations do not generally recognise coatings as an application very relevant to assisting deinking operations but more than one-third of organisations in the nanoparticle network are focused on nanocoating. Similarly, fibre technology is neglected in the nanoparticle network where there are only 2 organisations working on this technology. There is interesting scope for mutual learning between the two networks in relation to these areas. Gatekeepers identified in separate networks could act as catalysts in bringing organisations with a similar focus together (eg HP in relation to ink/toner technology and Imerys regarding coating applications).

Resistance to nano technological innovations may be due to both technical difficulties unresolved in resulting reasonable quality of recovered paper and conflict of interests amongst paper and ink manufacturers, printers, recycler and deinkers. The complexity of paper deinking and recycling which depending on a series of interrelated technological systems remains an obstacle at present. The gatekeepers who represent the channels of interaction between the two networks have a potentially significant role in changing this situation, both in terms of influencing technological change and contribute to the success of innovation.

The evidence does not suggest that the aspirations for nanoparticle innovations contributing to sustainability goals in print-on-paper are as yet being translated into practice in the emergent innovation networks identified. A more explicit and purposive role of key gatekeepers could contribute to the pursuit of this though there remain many technical uncertainties. The emergent tendency is oriented to the performance goals of printability rather than to those of deinkability.

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