Innovation in Resource-Based Technology Clusters

Investigating the Lateral Migration Thesis

The manufacture of biodegradable plastics from maize starch: a case of technological migration, adaptation and learning in South Africa

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Abstract

This paper explores the role of collaborative partnerships and linkages in the diversification process of firms, particularly those that have moved from primary resource-based activities into high-value niche applications. A two-year government funded project focused around the production of biodegradable plastics from maize starch in South Africa is used as a case study from which to "unpack" some of these issues. Although existing polymer processing equipment and imported high-grade maize starch were used to manufacture biodegradable plastic and no mass-manufactured products were generated through the research process, a notable outcome from the project was the lessons learnt/experience gained through the process of learning-by-doing and the systematic process of adopting, internalising and

Acronyms

A&AC	Agriculture and Agri-Food Canada
AMTS	Advanced Manufacturing and Technology Strategy
BEE	Black economic empowerment
CO_2	Carbon dioxide
CSIR	Council for Scientific and Industrial Research
DEH	Department of Environment and Heritage, Australia
DTI	Department of Trade and Industry
EU	European Union
IAM	Institute for Applied Materials
ICT	Information and communication technology
IF	Innovation Fund
IMS	Integrated Manufacturing Strategy
MCC	Magnesium Compound Consortium
N_2	Nitrogen
NRDS	National Research and Development Strategy
NRF	National Research Foundation
O_2	Oxygen
PLA	Polylactic acid
R	South African Rand
R&D	Research and development
SET	Science, engineering and technology
THRIP	Technology and Human Resources for Industry Programme
TNO	Netherlands Organisation for Applied Scientific Research
US	United States

1 Introduction

The South African government is centrally concerned with implementing and supporting programmes aimed at diversifying the economy away from its current dependence on natural resources into high-technology manufactures. Although South Africa is richly endowed with natural resources such as minerals, agriculture and energy, the advent of the knowledge-based society has highlighted that the availability of natural resources does not automatically confer a comparative advantage to a country rich in such resources. However, if the scientific knowledge embodied within the activities required to extract and process such resources is harnessed and broadened through local adaptation to suit other sectors, then resource endowments can be used a springboard for subsequent development. In addition, the further downstream a resource is processed, the greater the scope, potential and opportunity for diversification in high-value, non-resource-based, niche markets / applications.

The government recognises the important role that existing capabilities in the natural resource sector can play in the emerging system of innovation. Indeed, the fourth technology mission of the *National Research and Development (R&D) Strategy* (NRDS) emphasises "leveraging off resource-based industries and developing new knowledge based industries from them i.e. mobilising the power of existing sectors". Similarly, the DTI's proposed *Integrated Manufacturing Strategy* (IMS) aims at promoting knowledge intensity, value addition, and exports, and advocates the expansion of knowledge clusters and the continuous generation of intellectual property and new technologies to ensure future industrial competitiveness. These strategies have been followed by the *Advanced Manufacturing Technology Strategy* (AMTS), which aims to stimulate technological upgrading, facilitate the flow of technological resources to industry through new knowledge networks, and create an environment conducive to innovation through the supply of skilled people, technology infrastructure and funds. Sectors with the greatest potential to support the goals of the IMS and NRDS are prioritised, including advanced materials, product technologies, production technologies and information and communication technology (ICT) in manufacturing.

Despite this proactivity at the government level to provide an environment conducive to facilitating diversification, innovation and knowledge development in South Africa, there is a paucity of knowledge documenting how "know-how" and expertise at the firm level has emerged and evolved over time. In particular, understanding the factors that gave impetus to new product and process development, the type of human resources/absorptive capacities that facilitated it, the R&D process, the role of networks and collaboration, and the limitations that currently hinder the replication or advancement of such strategies is needed. Case studies are also needed that "unpack" the linkages and collaborative partnerships that were entered into to facilitate the diversification process in firms, particularly those that have moved from primary resource-based activities into high-value niche applications. In addition, understanding how capabilities and expertise in various areas have combined to assist in the migration of technologies from one industrial application/context to another are needed. Such information will go some way to ensuring that current government initiatives and programmes are well-targeted, appropriate and assist in fulfilling the broader challenges of science and technology development in the country in a sustainable and long-term manner.

This paper seeks to provide insight into these various issues by reviewing a THRIP-funded programme[1] undertaken between January 2002 and December 2004 focused around the production of biodegradable plastics from maize starch in South Africa. The case study is of interest and relevance for three reasons. First, while investigations into the manufacture of starch-based renewable plastics is not a new area of research, the South African experience involved the migration and adaptation of technological concepts and methodologies largely developed in Europe to meet the technological parameters and requirements of the local context. As such, the R&D process involved a combination of both basic "learning by doing" (local modification of existing thermoforming equipment and processes) as well as the systematic process of adopting, internalising and matching insights gained from interaction with international experts with those developed locally.

Secondly, it draws together three different, independent disciplines – food processing, polymer manufacturing and biotechnology – that became linked through two different research agendas; the need to broaden the application of a food product into niche applications, and to enhance R&D around polymers and polymer technology. Thirdly, the project involved, to varying degrees, a consortium of local and international research institutes, universities, manufacturing companies, and government organisations. Reviewing the various partnerships and linkages established between them is useful for formulating an understanding of critical issues involved in the innovation process such as the absorption capabilities of firms, how knowledge and technology is acquired, diffused and adapted, the importance of funding, the constraints involved in the innovation process, and how existing capabilities in other firms can be leveraged to ensure effective innovation, technology development, and product commercialisation in the future.

Before commencing with the local case study, the paper provides a brief review of the international experience of starch-based plastics and economic and environmental rationale for the move to manufacture bio-plastics and biodegradable plastics from renewable sources. The key features characterising the research endeavours of leading government organisations, research institutes and private companies will be discussed and the advantages and disadvantages of biodegradable starch-based plastics over conventional petroleum-based ones documented. Using this as a framework within which to situate the South African experience, a qualitative analysis of the manufacture of biodegradable plastics from maize starch in the country is then undertaken. The factors that led to the emergence of such investigations in South Africa, the different partnerships and networks that were established, the source of technology and funding, the outcomes of the research and constraints affecting the further development of knowledge and innovation in biodegradable polymer research will be assessed.

[1] The Technology and Human Resources for Industry Programme (THRIP) is one of a number of government-incentivised schemes currently aimed at facilitating technology and innovation in South Africa. It is managed by the National Research Foundation (NRF) and encourages the formation of collaborative partnerships between tertiary, private and public sector organisations and individuals.

2 Biodegradable plastics from renewable sources: the international experience

2.1 The environmental and economic rationale

Plastics are relatively inexpensive materials used for a wide variety of applications in industries such as surgery, hygiene, catering, packaging, agriculture, fishing, environmental protection, technical and other sectors. Material characteristics of low-density, low cost, ease of processing and flexibility in design give plastics superiority over other packaging materials. Most plastics and synthetic polymers currently manufactured, however, are produced from petrochemical compounds and there is a growing global concern about the future economic sustainability of using such non-renewable inputs in such short-term applications. More importantly, conventional petrochemical-based plastics are not easily degraded in the environment due to their high molecular weight and hydrophobic characters. Consequently, the disruption caused to ecosystems as a result of non-degradable materials in the environment has prompted decision-makers and the plastics industry worldwide to identify and develop durable bio-based alternatives in an attempt to effectively dispose of waste plastics (Narayan, 1997; *Farmers Weekly*, 2000; DEH, 2002; A&AC, 2003).

Research into new product development in polymers is increasingly encompassing a holistic "life-cycle thinking" approach. The impact of raw material resources used in the manufacture of the finished product and the ultimate fate (disposal) of the product when it enters the waste stream is increasingly being factored into the product design and engineering process (Narayan, 1997). As a result of this, a considerable amount of investment and R&D has been conducted worldwide to identify alternative feedstocks that can be used to ensure the environmentally-friendly nature of plastic materials. The biochemical industry (food, grain, sugar) is regarded as offering the best solution to build capacity for biodegradable plastics at the expense of the petrochemical industry or, conversely, it is believed that the petrochemical industry could benefit from its long-standing experience in processing by leveraging its inherent capacities and technology to develop alternative, renewable feedstocks (Narayan, 1997; DEH, 2002). While the international community views biodegradable sources as an alternative to petroleum-based compounds, it is also acknowledged that it is only viable for specific applications due to the unique physical properties of some polymers used (Narayan, 1997).

2.2 Biopolymers and biodegradable plastics

In essence, there are two types of degradable plastics: photodegradable and biodegradable plastics. In the former, the polymer or the additives have light sensitive groups directly incorporated within them. Exposure to physical agents, such as light, results in the gradual breakdown of the polymer into smaller non-degradable pieces leading to a loss in the structural integrity of the material concerned. A type of polyethylene is currently being marketed that includes a catalyst that triggers the thermal degradation of the polymer. In contrast, biodegradable plastics are those that are capable of being completely decomposed into their organic constituents (carbon dioxide, methane, water, inorganic compounds, or biomass) by means of the enzymatic action of micro-organisms. While such processes can be measured by standardised testing procedures, factors such as the type of polymer used, the additives, fillers, weight of the product, bacterial environment, temperature, and degree of humidity strongly influence the time take for a specific polymer to degrade.

Timescales can vary from a few months to a few years (FRIDGE, no date; DEH, 2002; A&AC, 2003).

In biodegradable plastics the core constituent is a renewable, natural resource. As such, they are often referred to as "biopolymers". The main sources of natural biopolymers include micro-organisms (bacteria, fungi), plants (crops, forests), and animals (livestock, insects, marine life such as shell fish and algae). Certain proteins and pectins have also been modified and adapted for use in biodegradable plastic production. The resins produced using these inputs can be converted into three types of biodegradable polymers: polylactic acid copolymers (these materials have a broad spectrum of properties but are largely aimed at applications presently held by polyesters, including fibres and packaging, and polystyrene); aliphatic/aromatic polyesters and polyester amides (while a wide range of property combinations can be obtained, these materials are generally aimed at applications held by polyethylene and polypropylene); and starch copolymers and derivatives (these are generally polyethylene and polystyrene replacements). The latter is the dominant type of biopolymer used (FRIDGE, no date).

2.2.1 Starch-based bioplastics

Starch, as a key component of many renewable raw materials, is becoming an increasingly important input to activities outside the food industry due to the variety of ways in which it can be modified. According to DEH (2002), starch is essentially a linear polymer (polysaccaride) comprised of repeated glucose groups linked by glucosidic linkages in the 1-4 carbon positions. The length of the starch chains varies according to the plant source but in general the average length is between 500 and 2 000 glucose units. There are two major molecules in starch – amylose and amylopectin. The alpha linkage of amylose starch allows it to be flexible and digestible. Starch-based biodegradable plastics may have starch contents ranging from 10% to greater than 90%. In the manufacture of plastics, starch may be used in three ways: as an adjunct to conventional plastics (6% starch); blended with synthetic polymers (60-70% starch); and as a thermoplastic (75-95% starch) (FRIDGE, no date). In order to be suitably biodegradable, the starch (amylose) content in such polymers needs to exceed 60% before significant material breakdown occurs. As the starch content is increased, the polymer composites become more biodegradable and leave less recalcitrant residues.

Often, starch-based polymers are blended with high-performance polymers (e.g. aliphatic polyesters and polyvinyl alcohols) to achieve the necessary performance properties for different applications this, however, influences the ultimate degradability of the plastic. Biodegradation of starch based polymers is a result of enzymatic attack at the glucosidic linkages between the sugar groups leading to a reduction in chain length and the splitting off of sugar units (monosaccharides, disaccharides and oligosaccharides) that are readily utilised in biochemical pathways. High-starch content plastics are highly hydrophilic and readily disintegrate on contact with water. At lower starch contents (less than 60%) the starch particles act as weak links in the plastic matrix and are sites for biological attack. This allows the polymer matrix to disintegrate into small fragments, but not for the entire polymer structure to actually bio-degrade (DEH, 2002).

Although the principle source of starch-based biopolymers varies across countries depending on the main source of carbohydrate available, generally, the main sources are corn/maize, wheat and legumes (United States, Australia), and potatoes (Europe). Other sources being explored include cassava (Thailand, India), and tapioca (Japan) (see Sriroth, 1997; Balagopalan, 2000; *Farmers Weekly*, 2000; CGPRT, 2003; Sun and Jianfeng, 2003; Greene, 2005).

Biopolymers can be used for a vast range of applications. While initial research efforts in the 1980s focused primarily on the use of polylactic acids in disposable packaging, agricultural film, and high-end medical applications (implants, sutures, slow-release drug delivery systems), more recent research has extended the market applications for bioplastics to include non-biodegradable products, such as apparel and textiles, which can be either recycled or incinerated (Table 1).

Table 1 - Market applications for bioplastics (A&AC, 2003, 10)

Biodegradable		Non-biodegradable
Packaging: ▪ Packaging bags and films ▪ Composting bags ▪ Loosefill packaging ▪ Edible packaging	Horticultural: ▪ Mulching films ▪ Greenhouse films ▪ Plant pots ▪ Soluble bags for plant care products	Apparel: ▪ Sports, active wear, and underwear ▪ Fashion blends with wool, silk and cotton
Objects often left on the ground: ▪ Golf tees ▪ Disposable dishes ▪ Firearm ammunition wads or shells ▪ Firework casings ▪ Cemetery decorations	Medical applications: Capsules ▪ Resorbable implants ▪ Suture threads, clips ▪ Orthopaedic fixations (e.g. screws, pins) ▪ Anastomosis ring ▪ Ligature clips	Textiles: ▪ Carpets ▪ Comforters ▪ Pillows
Eco-marketing/aesthetic: ▪ Hydro-soluble bags for baits ▪ Bank card ▪ Watch case ▪ Ball point pens, toys, gadgets		

A number of companies are now producing starch-based plastics throughout the world including Biotec GmbH (Germany), VTT Chemical Technology (Finland), EverCorn, Inc. (US), Novamont (Italy), EarthShell (US), AVEBE (US), Rodenburg BioPolymers (Netherlands), StarchTech, Inc. (US), and Vegeplast (France). The main player in Europe is Novamont, which owns 80 patents and related extensions. Rodenburg BioPolymers (Netherlands) has built a plant to transform potato wastes generated by the french fry industry for use in injection moulding. The plant capacity is said to be 36,000 tonnes per year. Its targeted markets include golf tees, controlled release fertilizers, combinations with paper, and temporary protection of engine openings (A&AC, 2003; Focke, 2003; FRIDGE, no date).

In addition to their biodegradable potential, another important environmental benefit associated with substituting synthetic petrochemical polymers with biopolymers is its contribution to reducing greenhouse gases. It is estimated that starch-based plastics can save between 0.8 and 3.2 tonnes of CO_2 per tonne compared to 1 tonne of fossil fuel-derived plastic. The range reflects the share of petroleum-based copolymers used in the plastic (*Farmers Weekly*, 2000; DEH, 2002). From an economic/industrial perspective, shifting towards the manufacture of bioplastics can also assist in diversifying agriculture out of food production. With each successive level of processing a raw material is subjected to, the scope and opportunities for use in a diverse range of downstream applications increases. Beneficiation not only increases the value of the original input, but assists in ensuring the sustainability of the industry in the long-term.

Furthermore, much of the manufacturing process and machinery used in making bioplastics is based on food science and food production techniques. Bioplastics and biodegradable synthetic polymers can be produced using existing plastic processing machinery, including thermoforming, various types of injection moulding, compression moulding, extrusion (films, fibres), and extrusion coating and lamination (DEH, 2002; A&AC, 2003). Leveraging off existing capabilities and know-how and laterally migrating them into other applications in this way not only contributes to reducing the costs of having to purchase new pieces of equipment but also helps to increase the rate of industry take-up and the diffusion of technology.

Biodegradable plastics are gaining market momentum around the world. Polymers made from renewable resources, particularly those derived from starch and sugar, are expected to account for 60% of the market for European Union (EU) biodegradables in 2010. By 2020, the share of polymers using conventional petroleum-based compounds are expected to only comprise 20-30% of all plastics manufactured in the EU. In the United States, the replacement of non-degradable plastics with biodegradable, renewable alternatives is also expanding although it is largely driven by traditional economic drivers such as price and performance (A&AC, 2003).

Despite this worldwide trend, there are a number of drawbacks associated with biodegradable plastics. Chief amongst them is bioplastics' low water solubility. Starch is hydrophilic and partially water-soluble. Articles made from starch lose their mechanical properties in humid environments and disintegrate when placed in contact with water. Corn starch plastic is also weaker and difficult to make transparent. Starch, moreover, in its native form is not thermoplastic. When untreated starch is heated, thermal degradation occurs before the starch melts and flows. Therefore it cannot be easily processed like conventional plastics. The degree of processing the starch has to undergo before it becomes useful considerably increases the cost of the finished product. Indeed, the cost of the finished product relative to other plastics makes it a deterrent to widespread production, particularly in less developed and less affluent societies. In a review of 170 international biodegradable polymer patents it was noted that the second generation polymers have been estimated at approximately 20% higher price, (Symphony/ EPI technology) than the commodity polymers typically used in packaging applications (FRIDGE, no date).

The industry is currently working toward bringing down the cost of manufacturing biodegradable polymers by increasing production capacity, improving process technology, and using low-cost feedstocks. A number of new starch-based technologies and advances are also being made in order to improve the performance of the material. Methods that are being researched in an attempt to improve the water resistance of starch include starch laminated films; using expanded bead technology to make starch foamed trays; and developing starch-fibre composites. Starch can also be "complexed" to form a variety of plastic products with differing performance properties. According to Novamont (Italy): "the specification of the starch, i.e., the ratio between amylose and amylopectine, the nature of the additives, the processing conditions, and the nature of the complexing agents allows engineering of various supramolecular structures with very different properties" (Pandley et al., 2005).

The use of nanotechnology is also being investigated. An EU consortium (called Bionanopack) involving eight organisations from Italy, Germany and Greece are developing nanocomposite food packaging using starch and clay. According to the Netherlands Organisation for Applied Scientific Research (TNO), "The overall aim of the project is to develop a new biodegradable food packaging material with low permanent gas (O_2, CO_2, N_2) and water permeability. The structure of the new material is based on homogeneously dispersed silicates (clay minerals) in thermoplastic starch obtained via polymer melt processing techniques." The consortium is being coordinated by the Institute of Industrial Technology, TNO, Eindhoven (Netherlands). The resultant nanocomposites produced can be used for a variety of different applications. Nanocomposites of this category are expected to possess improved strength and stiffness with little sacrifice of toughness, reduced gas/water vapour permeability, a lower coefficient of thermal expansion, and an increased heat deflection temperature, opening an opportunity for the use of new, high performance, lightweight "green" nanocomposites materials to replace conventional petroleum-based composites (Pandley et al., 2005).

It is important to note that most research and development programmes undertaken around the world with regard to innovating, developing and commercialising new biopolymer products and processes are undertaken in partnership or as part of a consortium. Partners include research organisations, tertiary institutions, shopping outlets, industrial conglomerates, manufacturers, and private firms. Networks extend locally and internationally and funding is usually shared amongst participants and outside government resources are often drawn upon. The degree of funding in such programmes is also substantially high – for example, in the STARPLAST research project, part of the Competitive Industrial Materials from Non-Food Crops LINK Collaborative Research programme, funding was provided for a duration of three years and amounted to GBP1 million, of which 50% was provided by research groups and the British government and 50% by industry. Furthermore, the time lags taken between the research and final commercialisation stage are significant (DTI UK).

Against this review of starch-based biopolymers and the nature of research activities undertaken abroad, the discussion now shifts to explore the South African experience of maize-based plastics which culminated in a THRIP-funded collaborative project in the late-1990s.

3 Starch-based plastics in South Africa: the THRIP project

Between January 2002 and December 2004 a collaborative project was undertaken in South Africa to develop and commercialise a biodegradable plastic using starch produced from maize as its principal feedstock. At the core of the project were three key institutions – the Centre for Polymer Technology (a division within the Council for Scientific and Industrial Research, CSIR), the Institute of Applied Materials (IAM, a research centre in the University of Pretoria) and African Products (Pty) Ltd. (the largest wet-mill producer of maize starch in Africa) – which provided the framework and agenda for the research. Through personal interactions and relationships established between members of these core institutions with other interested individuals and organisations, both locally and internationally, a series of additional linkages were fostered that were fundamental in broadening the scope of the project and providing critical inputs and know-how to enable technological learning and innovation to take place.

3.1 Origins of the research programme

The initial impetus for the emergence of the collaborative project can be traced back to three separate research agendas undertaken by various organisations and individuals that coincided in the early 2000s. Although no previous joint investigations between academic institutions and private enterprises had been made into exploring the possibilities of producing biodegradable starch-based polymers in South Africa prior to the commencement of the project, research into polymer compounds was well-established, particularly at the Centre for Polymer Technology at the CSIR in Pretoria. During the 1980s, two academics, both of whom would prove instrumental in establishing the research partnership, were employed at the Centre. Although one of the researchers subsequently left the CSIR to pursue his research interests independently, he retained contact with his colleague and kept abreast of developments at the CSIR. His independent research endeavours encompassed establishing his own manufacturing and R&D company, Xyris Technology CC, and undertaking exploratory visits overseas to broaden his understanding of the European experience of polymer research, specifically the manufacture of biodegradable plastics. He visited most of the leading companies and organisations involved in such research and established commercial contacts and linkages with some of the principle scientists. In 1996 he was appointed director of the Institute of Applied Materials (IAM) in the Department of Chemical Engineering at the University of Pretoria with the brief to establish a research institute that did collaborative and consultative work. His previous experience at the CSIR in polymer compound technology and in establishing a manufacturing business meant that he was well positioned to fulfil the brief and engage with other organisations involved in such research.

Within the CSIR, research into polymer compounds continued throughout the 1990s. Investigations extended into the possibility of replacing non-renewable petroleum feedstocks used in conventional plastics with natural, renewable alternatives. The viability and use of biodegradable fillers in packaging were explored as well as compostable plastic shopping bags. A key environmental question that emerged in South Africa in the late-1990s was the issue of non-biodegradable plastic bag disposal. Plastic bags constituted about 7% by mass of municipal waste in the country and were a very visible form of litter (Mail & Guardian, 2003). An inquiry was led into the feasibility of switching to photo-degradable and biodegradable alternatives (see FRIDGE). The CSIR was involved by virtue of its research into polymer compounds. Involvement in the development of an alternative environmentally-friendly plastic bag was seen by the CSIR as a key research agenda and an opportunity to not only advance research and knowledge in the area, but to utilise available laboratory equipment to produce and commercialise a product with a distinctive social and environmental benefit.

Within this broader research environment, a leading local producer of maize starch and derivatives, African Products, was exploring alternative downstream market applications for its products. Various possibilities were investigated including paint thickeners. However, the end use of starch in such applications was considered too expensive relative to other alternatives and the quantity produced. Consideration was therefore given to the possibility of entering niche "green" applications that would add value and would off-set production costs. Further, with rising oil prices, the attractiveness of starch as a replacement feedstock for petroleum-based plastics was increasing. The possibility of developing a cheap, biodegradable plastic derived from maize starch in South Africa was raised. Recognising that its research laboratories were unsuited to the development of plastics (R&D was mainly concentrated around food technology) and that it also lacked expertise in polymer compounds, African Products embarked on a strategy to establish links with other organisations capable of developing the concept further (Godfrey, 2005). One of these links was with the CSIR. African Products approached CSIR to explore alternative uses and markets for its starch products, particularly the production of an injection mould compound that was cheaper than conventional plastics, compostable, and suitable for a large (preferably overseas) market. The CSIR subsequently became the research partner as well as the project manager in the project (Godfrey, 2005). The CSIR, in turn, approached the IAM at the University of Pretoria to participate in the project due to its long association with the director.

3.2 Key features of the project

The guiding objective of the project was to develop and commercialise a starch-based plastic without the use of significant amounts of synthetic polymers. The resultant product needed to be relatively cheap and easily processable using existing plastics conversion equipment. The technical focus of the study was to improve rheology (melt flow characteristics) to the extent that the material could be processed on conventional injection moulders. Various additives that improve the water resistance of the biodegradable plastics were also to be evaluated (www.csir.co.za).

All three of the core participants recognised the potential micro- and macro-level benefits that would be gained by the efficient pooling of knowledge, capabilities and resources in the fulfilment of the project mandate. At the macro level, the spin-offs that would result would be medium to long term in nature and would encompass a social, environmental and economic dimension. The most important benefits would parallel those advocated by the international community: the efficient disposal of waste products; the replacement of a non-renewable input with a renewable, biodegradable one; and diversification away from primary agricultural production into advanced manufacturing. At the micro-level, the benefits would be specific to organisations involved. For the IAM and Centre for Polymer Technology, the benefits would largely be in the development of new knowledge (by students and staff) in advanced materials and the fulfilment of the directive to form collaborate partnerships outside the university. In the case of African Products, benefits would include not only the development and commercialisation of a new product that would be give them international competitiveness and provide the foundation for the establishment of partnerships overseas, but would also assist in the diversification of the company's product base and support its role as an environmentally-conscious firm.

3.2.1 Sources of technology, migration and learning

As evident from the earlier discussion of the international experience of bio-polymer and biodegradable plastics research and development, starch-based plastics is not a new area of inquiry. However, in Europe the base starch used is potato rather than maize, so the chemical challenges presented to the consortium were somewhat different to those undertaken overseas. Furthermore, until African Products approached CSIR with the proposal of diversifying starch into plastic manufacture, the level of product-related R&D in biodegradable plastics was reserved to a few key areas, most notably plastic bags and fillers.

A key outcome of the inquiry into the feasibility of switching to biodegradable plastic bags in South Africa was the high production costs, which negated against its widespread introduction (FRIDGE, no date). Researchers at the IAM realised that the commercial implications associated with developing starch-based plastics would be one of the greatest challenges that would have to be overcome in order for it to be viable in the long term. While starch on its own was cheap (R2 per kilogram compared to R10 per kilogram for plastic), and existing extrusion machinery could be used, the finished product would be considerably more expensive given the additional stages of processing needed to convert the maize starch into a product with the same material characteristics as conventional plastics. In order to be commercially viable, therefore, the final method selected would have to produce compostible plastics relatively easily and with high value.

The insights gained from the IAM's director's previous investigations in Europe, particularly in Germany, Italy and the Netherlands, regarding the best approaches to the manufacture of biodegradable plastics proved invaluable in setting the technical parameters of the project. Drawing on existing technology and research was seen an imperative to fulfil the criteria of the project and enable the pursuit of niche markets. In this regard, one of the key technical inputs came from the IAM's interaction with the TNO, the Dutch equivalent of the CSIR. The TNO, together with its partner university, had made great strides in polymer plastic technology. The TNO had found a way to produce biodegradable plastics relatively cheaply by using waste potato peels. Motivated by the need to find a way of disposing significant quantities of waste peels following a decline in demand for red meat and hence a drop in fodder requirements in the country, researchers in the Netherlands developed a process that combined the waste starch in the potato peels with synthetic polymers to develop a biodegradable plastic.

Polymer technology research at the TNO was also being extended to the development of new synthetic products, coatings and polymer materials capable of meeting special requirements imposed by industry, specifically those relating to protection, sustainability, decoration, providing a barrier effect against gases, corrosion resistance, electrical conductivity or luminosity. In order to achieve these effects, experiments were being conducted that combined plastics with metal, glass or ceramics at a macro (fibre-reinforced plastic), micro (coatings) and nano (biodegradable plastic) scale (www.tpd.tno.nl/; van Velzen, 2004; Padley et al., 2005).

The TNO's research into nanoclays was particularly interesting to the IAM as the applications were in niche applications (polymer electronics, coatings, membranes and environmentally friendly solutions for crop protection). The TNO had also undertaken research into the use of nanoclays in the production of water resistant films (which could withstand water for three months before degrading) which was of particular interest to local researchers given the prevailing debates around the issue of effectively managing and disposing of plastic bags. The TNO had also developed proprietary technology to disperse nanoceramic particles in a wide range of polymeric (coating) materials, which offered potential benefits in the injection moulding of investment castings. The TNO's knowledge of polymer materials, special processing steps and functional product requirements provided the basis for South Africa's commencement into the development new polymers and hybrid materials for products for niche, high-value markets.

Given the long history of polymer research in South Africa and the capabilities that had evolved in the two research organisations there was a base upon which many of the ideas gleaned from interaction with international experts could be transferred (i.e. "migrated") and internalised. While interaction with international research organisations was critical for establishing the main hypotheses, methodologies and technical parameters for the project, there were a number of differences with the approach adopted by the South African team that necessitated a considerable amount of "learning by doing", systematic local adoption and internal product innovation. In the first instance, the project used maize starch as the principal renewable input. Corn starch is used widely in the United States in the manufacture of biodegradable plastics, however, it is generally converted (by fermentation) into polylactic acid (PLA) before being processed further. In South Africa, maize is the dominant carbohydrate crop; however, it is not directly suited to the manufacture of plastics due to the low amylose content. A starch has to have an amylose content greater than 60% in order to be used without the addition of a synthetic polymer compound. Consequently, starch containing enhanced levels of amylose had to be imported in order for the project to commence. African Product's association with Penford Australia Ltd (a subsidiary of Penford Corporation, a US supplier of speciality starches), however, provided the consortium with access to a variety of maize – known as Hi-Maze – with a sufficiently high level of amylose to undertake process-related research without prior fermentation (www.penford.com.au).

Secondly, one of the objectives of the project was to evaluate the use of various additives to improve the water resistance of the biodegradable plastics. The use of nanocomposites in polymer production was therefore a core area of interest given their ability to improve the material properties of the resultant plastics, particularly in terms of rigidity, strength, and barrier characteristics. Nanocomposites could also assist in maintaining a level of transparency. The types of nanocomposites that were experimented with during the project were broadened to include hydrotaclite, largely as a consequence of the interest expressed by the Magnesium Compound Consortium (MCC) for the use of such composites in investment castings.

While the project drew extensively on the work done abroad, no licensing agreements were entered into although visits from international scientists did take place. Most of the adaptation and R&D was done locally and drew on the expertise and know-how of the various scientists and researchers at the IAM and the CSIR. As an interdisciplinary materials research group, the IAM has a high-level skills base encompassing physicists, chemists, chemical engineers, material scientists, and metallurgists with a range of technical and application experience. A similar skills base is available at the Centre for Polymer Technology. At the IAM, approximately two PhD and two Masters degrees were generated during the project and various undergraduates were involved in the nanocomposites research. At the CSIR around six people were involved to varying degrees in the project.

While existing facilities and polymer extrusion equipment at the CSIR were used throughout the duration of the project, a certain degree of know-how was needed in order to ensure the material was suitable for use on conventional machinery. While it is widely asserted that existing production techniques can be used to produce biodegradable products, initial tests undertaken at the CSIR highlighted a number of difficulties associated with extrusion using conventional thermoforming machinery. In particular, slower blowing rates, difficulties in maintaining thickness, and reduced material strength were encountered (FRIDGE, no date).

3.2.2 Funding

In terms of funding, various sources were approached by the three leading partners prior to the commencement of the project. A proposal was first submitted to the Innovation Fund. The Innovation Fund (IF) provides resources for technologically innovative R&D projects that will not only generate new knowledge, but also widespread national benefits in the form of novel products, processes or services (www.innovationfund.ac.za). The application, however, was unsuccessful. The main concerns raised by the NRF related to the commercial risks associated with the project and the fact that there was no clear information to show how the project would result in revenue generation, black economic empowerment (BEE) and job creation. An attempt was also made to obtain EU Funding (5th Framework) to take research into plastic film development further (blow film is used in the manufacture of plastic bags).

Given the highly competitive nature of the funding programme, the application also failed (according to one of the participants only 14% of the EU programmes applied for were successful at the time of the enquiry). African Products then suggested that the project parameters should be refined and the scope reduced and that they try the government incentivised Technology and Human Resources for Industry Programme (THRIP). Four proposals were submitted to the National Research Foundation (NRF) over a space of two years before funding was secured for a three year research period. An extension of one year was also granted. THRIP funding enabled the IAM to go into an equal partnership with the CSIR.

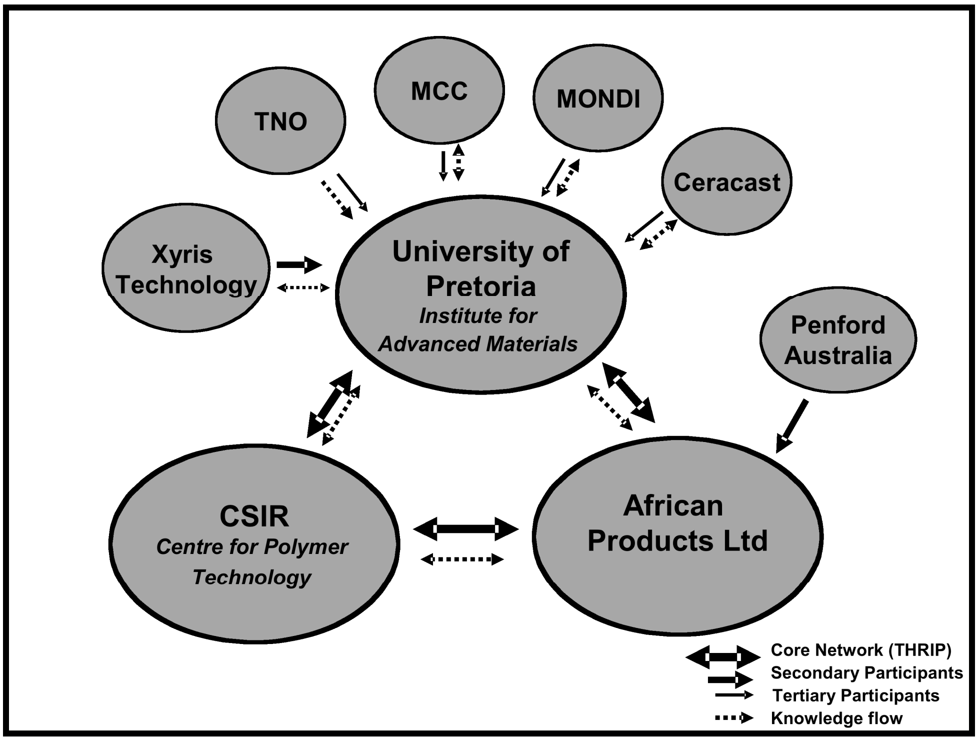
The THRIP is managed by the NRF. The basis of the programme is that for every R2 invested by the private sector in a science, engineering and technology (SET) project, R1 is provided by the NRF. This can, however, vary according to the project being undertaken. The main criteria that had to be fulfilled by the consortium in order to secure funding were threefold. First, the project leader and project had to be based at a higher educational institution or Science Engineering and Technology Institution (SETI). Second, the research had to be of a high standard, have clearly defined technology outputs, and involve at least one higher education institution and one industrial partner. Third, at least one registered South African student had to be involved in and trained through the research for every R150 000 of THRIP investment provided (http://www.nrf.ac.za/thrip). CSIR acted as both the project manager in the project and the intermediary between the various participants. African Products and Xyris Technologies, as the two private enterprises involved in the project, contributed approximately R400 000 to the project, of which the largest share (R300 000) came from African Products (Godfrey, 2005). The balance was provided by THRIP in three instalments – R381 000, R327 000 and R260 000.

While the resources provided by the industry partners and the THRIP enabled the project to commence, problems were encountered during the application and funding process. The participants found the application process very time-consuming and lengthy. Funding was only secured after the fourth attempt and after two years of trying. Moreover, the researchers felt constrained by the parameters and timescales imposed by the funding programme. The lead researchers argued that researching, developing and commercialising products such as biodegradable plastics requires long timeframes and progress is often difficult to predict. Frequent modifications, testing and trials slow down the process, particularly as the composting rate of the plastics being designed extended from anywhere between a few weeks to a number of months. Participants argued that while in hindsight more accurate planning at the commencement of the project may have prevented some of these problems from arising and enabled the commercial benefits to be realised earlier, a more flexible approach to funding would have been more beneficial given the nature of the research project (Godfrey, 2005).

3.2.3 Partnerships and networking

Partnerships and networking underpin the project and provide it with an element of vibrancy and dynamism. They also played a critical role in advancing knowledge in the area of bio-based polymers in South Africa. The starch-based plastics network is complex, both in terms of the number of partners involved and the extent of their involvement (Godfrey, 2005). The primary (core) set of relationships are between the three THRIP partners (the IAM at the University of Pretoria, the Centre for Polymer Technology, CSIR, and African Products (Pty) Limited, based in Germiston). Within this formal network there are two core sets of relationships which extend back to the 1980s and 1990s. One is between the IAM and the CSIR Polymers Technology group, the other between the CSIR and African Products. Both of these rely heavily on personal interaction for their success. A very important link exists between Xyris Technology CC (a sponsor of the research) and the University of Pretoria. Xyris was founded by the director of the IAM before he joined the University and the company is interested in commercialising the final research results. The relationship between the IAM and TNO was vital for providing the technological focus of the project. The long-standing relationship between African Products and Penford, Australia was also crucial for providing a source of suitable starch feedstocks needed for the manufacture of the plastics. Both these latter three sets of relationships can be termed "secondary relationships". A third (tertiary) level of partnerships exists in the network. The IAM also has linkages with a number of local private companies interested in polymer compounds (although not specifically starch-based) and the commercial opportunities that could arise from the research. These include the Magnesium Compound Consortium (MCC), Mondi, and Boart Longyear Ceracast. A brief description of some of these affiliated organisations and companies and their contributions to the project will be elaborated below and are highlighted in figure 1.

Figure 1 - Participants involved in the network and their relationship to each other



African Products and Penford, Australia

African Products, which initially belonged to Tate & Lyle in the 1970s, was sold to Anglo American in the late 1970s. It was bought by Tongaat in the 1980s. It is a wholly-owned subsidiary of the corporation and has been the second-largest contributor to profits (after Tongaat's sugar division) for the last four years (*Engineering News*, 2003a, 2003b). African Products entered the maize starch plastics project as an exploratory exercise; using the experience it had already developed with the CSIR to establish additional downstream markets for its products. African Products was interested in eventually working on a large scale. The project was therefore of great interest to African Products as it not only give them the possibility of utilising their starch in other niche areas (particularly for the international market), but that the final product was biodegradable. However, in order to be commercially viable, 100,000 tons of the base compound had to be produced per year to warrant setting up an injection mould plant. Although investment in the project was viewed by African Products as a risk venture with potential commercial benefits (Godfrey, 2005), their role in the broader project was very important. Not only were they a principal financier, but played an important role in the sharing and dissemination of knowledge. Two people from the R&D department at African Products worked with the CSIR on the project.

Moreover, African Products' relationships with other international companies involved in the production of maize starch were also of significant value to the project. African Products has a technical licence agreement with Corn Products, of the US, one of the three largest wet millers in the world. More importantly, it has an agreement with the US-owned Penfords of Australia. The company produces modified starch, particularly waxy maize starch modified products. Penford Australia was instrumental in developing the first seed crop of Australian-grown high amylose corn in the 1970s – HiMaize). Penfords was African Products' agent in Australasia and African Products was Penfords' agent in Africa (www.penford.com.au).

IAM, MCC and Boart Longyear Ceracast

The Magnesium Compound Consortium (MCC) and Boart Longyear Ceracast are research partners, but are not directly part of the THRIP agreement. Both are looking for particular polymer compounds that may arise from the maize-based starch research, which could facilitate the development of new products using their existing manufacturing techniques.

The Magnesium Compound Consortium (comprising Chamotte Holdings, Altona Chemicals, University of Pretoria, Pretoria Technikon and one private individual) is based in Chamotte Holdings, Midrand. Chamotte Holdings is primarily a mining company operating a magnesite (magnesium carbonate) mine near Malelane and chalk mine near Baberton, Mpumalanga. The magnesite is used to produce several grades of magnesium oxide and magnesium sulphate, which is supplied in bulk as commodity chemicals. The MCC is funded by the NRF and involves nine or ten researchers at any one time (Godfrey, 2005). The THRIP consortium became involved with the MCC through the IAM, which became interested in the MCC's investigations into the possible synthesis of magnesium hydroxide, hydromagnesite and, specifically, hydrotalcite. Hydrotalcite is an additive to plastics and MCC is investigating ways in which to can replace toxic heavy-metal salts currently used as heat stabilisers in plastics manufacturing (Engineering News, 2003c). The IAM was exploring the use of hydrotalcite (an anionic clay) as a nanocomposites in the production of biodegradable polymers and thus approached the MCC into acquiring hydrotalcite samples when Chamotte Holdings goes into production. Although no formal network exists, ideas are traded between the MCC and the IAM and, consequently, the rest of the THRIP network.

Boart Longyear is a member of the Anglo American group and is a leading supplier of products, processes and services to the natural resource, construction, quarrying and other industrial sectors both locally and worldwide. Boart Longyear Cerecast was established in 1984, and is situated in Postmasburg, South Africa. Ceracast was one of the first companies to start manufacturing precision castings for specialised applications in South Africa, particularly in the mining industry (e.g. coal borers, taper bit bodies, jackhammer components, conveyor belt scrapers). In 2003 the decision was taken in Ceracast to move into wax-processed castings as a means by which to broaden their customer base and diversify their product range. The company had traditionally used a plastisol process. Ceracast is currently one of only two casting plants in the world that uses and manufactures urea as well as wax as a moulding material (*Engineering News*, 2005). Ceracast became involved with the THRIP project through its interest in exploring ways in which the waste materials from ceramic formulations could be used in the production of degradable starches, particularly in coatings. Such research has been explored extensively at the TNO. Collaboration between Ceracast and the THRIP consortium is in its early stages.

IAM, CSIR and Mondi

Mondi, one of the leading paper manufacturers on the continent, is another Anglo-American owned company with whom the network is working. Mondi's interest in the project stems from the potential commercial benefits that could result from the successful development of a biodegradable plastic. The company had an initial agreement with the project team for the production of compositible seedling trays, which were the first marketable products to be produced by an IAM student in the CSIR laboratories. Mondi also expressed interest in the manufacture of disposable packaging for specialised applications that only degraded after a certain period of time.

One of the problems experienced by the company in the European market was the low rate of water permeability of the packaging products produced. In order to withstand the climatic conditions of the region such products, particularly paper bags, would have to be coated with a plastic layer that was impermeable in the short term but could be totally recycled as paper. When paper contains more than 5% plastic it is recycled as "mixed plastic" in Europe, whereas if it contains less than 5% plastic it can be recycled as paper. The research group's interest in developing coatings for paper bags and advancing paper towards plastic film properties (and association with the TNO where such technology was available to achieve this) was therefore seen as potentially beneficial to Mondi. For the research group, interaction with Mondi would provide access to an international market for its products, particularly as the South African market was regarded as being too small to sustain the scale of commercialisation needed to make the project feasible in the long-term. Mondi already had access to overseas markets which could be used and leveraged in order to secure and broaden the commercial scope for new applications (Focke, 2003).

<u>IAM and Xyris Technology CC</u>

Xyris Technology CC was established in 1990 and is a small custom plastics additive compounder in Bashewa, South Africa. The company's product line includes flame-retardants, corrosion inhibitors, barrier additives and purging compounds. Xyris Technology has been involved in polymer related research for a considerable length of time, including the development of technology for the controlled photodegradation of polyethylene and polypropylene. The director of the company is closely affiliated with research and development work related to biodegradable plastics at the IAM at the University of Pretoria (www.xyris.co.za). The company's main aim is to use these materials for manufacturing sapling pots and producing a cost-effective material suitable for film blowing. In terms of its involvement in the consortium, in addition to its financial contributions, Xyris Technology CC is poised to become the applications partner. Although it currently lacks the capacity to produce products of the quantity envisaged by African Products, these details will be negotiated once a suitable compound has been developed (Godfrey, 2005).

In terms of the success of the networking, partnerships and interaction has facilitated knowledge sharing and the dissemination of know-how and expertise in specific areas. Godfrey (2005) points out that knowledge transfer between the partners is regular and intensive. One way in which the dissemination of information and ideas occurred was via the informal interaction between staff, students and project leaders. Knowledge transfer also occurred through the frequent ad hoc meetings at the CSIR (mainly to discuss the work and the direction of research), the formal quarterly meetings of the core partners (at which the organisation of work and research progress was monitored), and the bi-annual formal meetings with peripheral partners. A high level of trust and mutual respect underpins the relationships between the various participants as all are bound by the need to develop a technology and product which cannot be developed in isolation (Godfrey, 2005). The nature of such relationships ensures the flexibility of the network and the general lack of conflict or tension. Godfrey (2005) points out that another factor that has reduced the importance of formal agreements, particularly with regard to intellectual property rights, is that the research is not yet close to producing a product that can be commercialised.

The relationships in the network were also shaped by the requirements and conditions of THRIP (Godfrey, 2005). While the core members of the consortium are senior personnel, the involvement of students and researchers at different levels has ensured a broad base of exposure to the research objectives and methodologies. It is clear that trust, ability and hard work have been critical to the effective function of the consortium. Active networking begins among colleagues at work, and is slowly developed with other colleagues at outside institutions and may take years to consolidate. Felicitous meetings and timing also play an important role in putting the 'right' people in contact at particular times (Godfrey, 2005).

3.2.4 Results of the study

The primary objective of the research project was to commercialise a suitable biodegradable plastic from maize-starch. Although this objective had not been reached at the end of the funding programme, participants in the project assert that significant advances had nevertheless been made and that most (80%) of the key milestones had been reached. In terms of meeting African Product's objectives of finding niche applications for maize starch, two products were successfully developed and the research team is still looking into a third. Polymer compounds developed and under trial using equipment and laboratories at the CSIR include seedling trays, pot plant holders, food containers, and golf tees. The focus of the project has now shifted to the commercialisation of a product that would be economically viable to produce.

Researchers assert that in assessing the outcomes of the project consideration should also be given to a number of additional spin-offs which resulted during the course of the R&D process and testing stage. These have implications for the future success of the project. In the first instance, a food store has expressed interest in replacing the polystyrene currently used for packaging with a biodegradable product and is prepared to pay a premium for an environmentally-friendly product. Such interest has motivated the research team to continue its R&D endeavours (Godfrey, 2005). In addition, Sappi (the world's largest producer of coated fine paper) is interested in the possibilities offered by the seedling tubes being developed by the IAM and CSIR. Such products could be of significant economic value in the future as the company loses a sizeable percentage of young saplings annually. It is alleged that protection afforded to the young seedling by encasement in biodegradable tubes would boost survival rates. The challenge, however, is to develop a tube that can degrade fully within 3 and 6 months. In addition to improving the materials of the tube, current research by the research group is also focused on developing a root pruning system to assist in the growth process and trials are in the advanced stage. Tests are still being run on new coating compounds (modified hydrotalcite calsys) and the MCC and Ceracast are still interested in the commercial possibilities of the product in injection moulding. Scale-up trails are being conducted with the moulding compounds and commercialisation is envisaged for 2006.

Another important spin-off that resulted from the project was the advancement of capabilities and know-how in the area of polymer technology and materials science. In particular, knowledge transfer occurred between the various researchers involved in the various aspects of the innovation process and new areas of expertise were developed, specifically amongst students and young graduates at the CSIR and IAM. Knowledge sharing also existed with the African Products team which met with the CSIR every two months in order to discuss the developments of the project. Results and experiences were documented in research reports, dissertations, theses, journal articles, and presentations at conferences and disseminated to a wide range of international and local scientists and researchers.

Researchers involved in the project assert that there were three reasons why the project failed to reach the commercialisation phase. First, the technology is still at an early stage of development and more money and time would have to be invested to make it viable. Second, the aging problem of the starch requires the addition of expensive additives which raises the cost of the finished product. Thirdly, African Products lost the licence for Hi-Maize. Access to a source of competitively priced raw material inputs was one of the main reasons why the project was able to commence. The only starch that produced the results required by the team was Hi-Maize, which was acquired through African Products' association with Penfords. The loss of the licence agreement towards the end of the project meant that the high costs of acquiring this raw material from elsewhere (e.g. National Starch) would make the final products uneconomical for the mass market. According to African Products, the reason they lost the licence was the high cost of importing the Hi-Maze starch as well as the lack of demand for the starch. There was not enough demand within South African to cover the cost of purchasing the Hi-Maze starch and this made holding on to the licence very expensive for African Products and as a result they relinquished the licence as well as their participation in the project. However, African Products still maintains a relationship with the CSIR on other projects. The current emphasis of the project is on the development of niche markets.

The participants also raised the issue of access to a continuous source of funding as a constraint to the future commercialisation of the R&D endeavours. Obtaining alternative sources of funding is complicated for projects like this one which rely heavily on staff and students at research universities for their success. The criteria placed on various participants cannot always be met (Godfrey, 2005). At the same time, having already tried the Innovation Fund and drawn on THRIP support, the researchers are not sure where future investment will sourced.

Consideration of the implications of these factors is critical for ensuring the continuation of research efforts in this area. Indeed, in terms of the future of the consortium and research into biodegradable plastics, it is evident that success will hinge on developing a product which can compete on price with current plastics for a large market. The market will be guaranteed if attitudes to the issue of the environmental benefits of substituting renewable inputs for non-degradable ones. At this stage it is unlikely that the government will support the move to bio-based polymer production on a large-scale. The likelihood of production of degradable polymers in South Africa seems low, moreover, due to the fact that big players can't keep up with demand for traditional polymers. Big players are furthermore keen to stimulate a strong recycling industry rather than replacement (FRIDGE, www.nedlac.co.za). Polymer compound research will continue, as the major knowledge benefit is in advanced polymer compound technology, and the opportunity for students to be involved in cutting edge research in the field and publishing in scientific journals. The parameters and objectives may, however, be reworked as new ideas are assimilated and modifications and adaptations dictate. Competition from another source is not of paramount concern at this stage.

In sum, the plastics-from-starch project highlights a number of important things that need to be born in mind in the interest of advancing industrial development and science and technology in the country. Firstly, it is evident that the capacity for technological learning and innovation in research institutions in the country is high. The project depended on an advanced set of capabilities amongst the participating institutions and organisations. Such a skills base and the ability to internalise and advance know-how were critical in migrating ideas and technological processes generated and perfected in Europe to South Africa. Technological adaptation, learning by doing and close interaction between participants underscored the R&D process. This was necessitated by the fact the South African study used a different type of feedstock in the plastic production process and the choice of compounds used in the experiments involving nanoclays composites (hydrotalcite, which is anionic), which presented significant chemical challenges that had to be overcome relatively early on. Furthermore, the South African team were also looking to produce a plastic that incorporated no synthetic polymer compound in its manufacture.

Secondly, financial support from the incentivised government funding programme, THRIP, was critical for commencing with the innovation process. The researchers approached various organisations locally and internationally in order to secure funding. However, it was only after THRIP agreed to fund a portion of the project that the consortium was officially established and research commenced. While internal funds will be used to cover project costs once THRIP comes to an end, this is only an interim measure and securing future R&D funding to advance research in the area is a core priority of the research group.

Thirdly, networking and partnerships were instrumental in driving the project and providing the resources and expertise needed to facilitate technological learning. The European success of R&D and commercialisation of biodegradable plastics has been underpinned by collaborative undertakings and close involvement of numerous public and private institutions and individuals. Given the range of skills and expertise needed in such a research endeavour (materials science, chemistry, metallurgy, plastics manufacture), R&D in biodegradable plastics is seldom undertaken in isolation. Research networks in Europe comprise government ministries, donor organisations, universities, research institutes, and private industries. Furthermore, most of the leading manufacturing companies involved in polymer manufacturing around the world have a diversified product and expertise base and have strong links with partner universities. In South Africa, the project depended not only on the skills and expertise within the three core participants, but also on their linkages with other individuals and organisations providing funding, technological insight, market opportunities and material inputs. Although great advancements were made, no intellectual property was claimed or shared between the participants.

Lastly, the project also highlights the importance of local demand in the R&D and product commercialisation process. In Western Europe, although the cost of manufacturing biodegradable plastics is acknowledged to be greater than that for conventional plastics, the associated environmental benefits of a suitable biodegradable alternative outweigh the costs. Moreover, it is seen as an opportunity to move away from a non-renewal input to a more renewable one. Such a drive is widespread and supported by both private and public sector officials and leading retailers throughout the continent. Consequently, such a high level of demand has resulted in significant R&D and product development efforts. By contrast, in South Africa, demand is reserved to a few select parties interested in the commercial applications rather than the environmental benefits of starch-based biodegradable plastics. Cost is seen as a major deterrent to the widespread replacement of conventional petroleum-based polymer bags. In addition, it was discovered that using starch for the production of plastics also caused accelerated wear and tear of the machinery, thus increasing depreciation costs and the overall cost of production. This cost would have to be passed on the consumer, making the plastics more expensive than conventional plastics. Therefore, until demand shifts from an economic to environmental focus, the parameters of the project will always be narrow in scope and concentrated on the production of niche products such as golf tees, flavoured dog bones, specialised packaging, seedling tubes and pots. A major drive would have to come from the government for a change in legislation in favour of biodegradable plastics, as well as increased government funding for R&D. This will allow suppliers of starch like African Products to have increased demand and push the prices of biodegradable plastics down, making them more competitive against conventional plastics.

4 Conclusion

This paper presented the results of a qualitative review of a collaborative project undertaken between 2002 and 2004 to manufacture biodegradable plastics from maize starch. The case study provides the opportunity from which to explore the micro-dynamics of the innovation process in South Africa and the manner in which firm capabilities evolve and develop over time. In particular, it showed how different, independent research agendas and quests for new opportunities amongst individuals undertaken over a long time combined through mutual interaction and collaboration. It demonstrated how expertise and resources were effectively pooled and brought together from various sources to establish a research environment conducive to innovation and learning and how technological processes and techniques used elsewhere were able to be modified and adapted locally. It also highlighted that although at the end of the funding programme a product had not yet been commercialised, significant advances had been made in developing products suitable for future commercialisation, most notably biodegradable compounds for seedling trays and golf tees. The commercialisation of moulding compounds is envisaged for 2006. A number of intangible benefits also resulted, specifically a broadening of advanced capacities through knowledge transfer and learning by doing. The case study also revealed the importance of private and public sector funding in the R&D process and the challenges associated with matching the unpredictable nature of the research process with established parameters and timeframes. From a government perspective, such insight is needed in order to understand the strengths and weaknesses of the prevailing innovation system and the challenges involved in going forward with national strategies aimed at advancing science and technology and manufacturing in the country.

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5 References

A&AC (Agriculture and Agri-Food Canada)., (2003): "Bioplastics", Report prepared by PRA Inc. and Canadian Agricultural New Uses Council (CANUC) for Agriculture and Agri-Foods Canada, 29 August.

Balagopalan, C., (2000). Integrated technologies for value addition and postharvest management in tropical tuber crops. Central Tuber Crops Research Institute, Sreekariyam, Thiruvanathapuram, Kerala, India.

CGPRT., (2003): "Biodegradable Plastics from Crops: Implications from New Project Japan, CGPRT Flash, Vol. 1 (4), 1.

DEH (Department of Environment and Heritage)., (2002): "Biodegradable Plastics – Developments and Environmental Impacts", Nolan-ITU Pty Ltd, Prepared in association with ExcelPlas Australia, Department of Environment and Heritage, October.

DTI UK (Department of Trade and Industry): Plastics from Maize, LINK Collaborative Research, www.dti.gov.uk.

Engineering News., (2003a): "How maize is wet milled – African Products", Martin Creamer's Engineering News, 7 March.

Engineering News., (2003b): "R100m expansion envisaged", Martin Creamer's Engineering News, 7 March.

Engineering News., (2003c): "Research project under way for safer plastics manufacturing", Martin Creamer's Engineering News, 23 March.

Engineering News., (2005): "Boart Longyear Ceracast division bought out", Martin Creamer's Engineering News, 15 August.

Farmers Weekly., (2000): "A bright future for crops converted into plastic?", Farmers Weekly, 12 January.

Focke, W.W., (2003): Starch-based plastics in Europe, Presentation, Institute of Applied Materials, Department of Chemical Engineering, University of Pretoria, October.

FRIDGE (no date)., Socio-economic Impact Assessment of the Proposed Plastic Bag Regulations, Report, www.nedlac.org.za.

Godfrey, S., (2005): "Power and Knowledge: The role of industry partners in knowledge-intensive networks in new materials development technology", Industry & Higher Education, April, 189-197.

Greene, J.P., (2005): "Australia Biodegradable Plastic Research", Presentation, Department of Mechanical Engineering, Mechatronic Engineering and Manufacturing Technology, California State University, Chico, 31 May.

Mail & Guardian., 2003: "The end of the plastic bag?", Mail & Guardian, 2 June.

Narayan, R., (1997): "Commercialising Technology: From Laboratory to the Marketplace – A Case Study of Starch-based Biodegradable Plastics Technology", Department of Chemical Engineering, Michigan State University.

Pandley, J.K., Kumar, A.P., Misra, M., Mohanty, A.K., Drzal, L.T., and Palsingh, R., (2005): "Recent advances in biodegradable nanocomposites", Journal of Nanoscience and Nanotechnology, Vol.5 (4), 497-526.

Sriroth, K., (1997): "Development of Biodegradable Plastics Using Tapioca Starch at Kasetsart University", Paper presented in International Symposium on Biodegradable Plasics Using Tropical Farm Products, Tsukuba Science City, Japan, 14-16 October.

Sun, X. and Jianfeng, Z., (2003): "Bioplastics derived from starch and poly (lactic acid)". ACS Symposium on Materials from Agriculture Products, New Orleans, LA, 23-27 March.

Ulphard Thoden Van Velzen, U.T., (2004): "R&D and innovation of bioplastics in the Netherlands, Presentation made at the IBAW - BCPN meeting, 26 April.

5.1 Internet references

African Products – www.africanproducts.co.za and www.tongaat.co.za

Centre for Polymer Technology, CSIR – www.csir.co.za

Institute for Applied Materials, University of Pretoria – www.up.ac.za

Penford Australia Limited – www.penford.au.com

THRIP – http://www.nrf.ac.za/thrip

TNO – www.tpd.tno.nl/

Xyris Technology – www.xyris.co.za