WINDESHEIMREEKS KENNIS EN ONDERZOEK nr. 55

From monomer to macromolecular network: the plastic hotspot

Margie Topp

Windesheim makes knowledge work

Windesheim

The image of the Zwolle city seal on the cover page can be found in the article "Two Seals" in: Verslagen en Mededeelingen van de Vereeniging van Overijsselsch Regt en Geschiedenis, dl. 6 ("Reports and Announcements of the Overijssel Law and History Association, Vol. 6") (Deventer, 1871), pp. 112-113. This concerns a description of the two seals that Mr. Cost Jordens presented to the Association in 1871. The seal depicts the archangel Michael defeating evil in the form of a dragon. The Greek philosopher Aristotle claimed that ignorance is the root of all evil. Hence, Windesheim research aims to defeat ignorance.

Colophon

Windesheimreeks Kennis en Onderzoek nr. 55

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From monomer to macromolecular network: the plastic hotspot

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From monomer to macromolecular network: the plastic hotspot

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Lectoraat Kunststoftechnologie/Professorship for Polymer Engineering

It was my father's idea that I should study chemistry.
As a 17 year old I did not particularly care about chemistry. I actually wanted to study French or music, but my dad planted the idea in my head that I should study chemistry. And this was solely based on his assumption that I was not too bad at it.

It took, however, until my second year at university before I came across a topic that I liked, which was Polymer Chemistry! The door to this world was opened to me by none other than professor Challa and I was finally sold.

Now, 25 years after starting my studies, my love for Polymer Chemistry has grown to the proportion of this inaugural address for the Professorship for Polymer Engineering.
Here's to you dad.


From monomer to
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the plastic hotspot.

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Samenvatting

Niet alleen het gebruik van plastics is de afgelopen jaren gegroeid, ook de eisen die we aan de materialen stellen zijn toegenomen. Daar staat tegenover dat door de opmars van 3D-printen ook het scala aan mogelijkheden is uitgebreid. De economische crisis en de schaarste aan olie hebben tot nieuwe uitdagingen geleid, waardoor bedrijven nog energiebewuster hebben moeten leren produceren en waardoor lichter construeren, van bijvoorbeeld auto's door middel van composiet, een nog grotere boost heeft gekregen. Er is ook een omslag gekomen in de perceptie van de consument ten opzichte van gerecyclede materialen. Waar het vroeger stond voor vies en kwalitatief minder goed, is het tegenwoordig gewenst.

Het lectoraat Kunststoftechnologie heeft altijd al samengewerkt met de lokale industrie en aangezien de industrie heel divers is, heeft het lectoraat daar haar brede oriëntatie aan te danken. De huidige vier programmalijnen zijn: recycling, hybride ontwerp in composiet en duurzaam produceren waaronder ook de programmalijn 3D-printen valt. In deze publicatie wordt een aantal voorbeelden van mooie reeds behaalde resultaten getoond. Ook wordt uitgelegd waar naartoe gewerkt gaat worden in de toekomst, de zogenaamde stip op de horizon voor elk van de programmalijnen: ontwerpgereedschappen voor snelle innovaties (duurzaam produceren), de effecten van gebruik en recycling op de materialen (recycling), het dissemineren van kennis en co-engineering (3D-printen) en hybride ontwerp (composiet).

Preface: things will have to change

In today's world, plastics and composites are so common we hardly give them a second thought. It is not until we cycle (yes, cycle, this is Holland after all) to the collection points with our bags of plastics for recycling or until we see a broken toy or detect a failure in one of our household appliances, that we actually think about our use of plastics. And truthfully, when it comes down to one of the above scenarios, we are actually a bit annoyed by it! And plastic ends up in the bad books!

It hardly needs any debate as to why modern-day society needs plastics. We want durability, we want lightweight, we want convenience, we want packaging and we want material mechanical properties from an extreme spectrum. Polymer Chemistry can provide that! However, as with all man-made creations, we need to ask ourselves: How much of it do we actually need and at what cost? Do we really need those plastic bags or new mobile phones? Do we really need to fly across the globe as often as we do? Although the opposite may also be true. A paper book may be made from natural materials, but an ebook saves trees!

The graph on the next page is an example of the difference a clever redesign of airplanes was able to achieve. Air traffic has gone up by 53% since the year 2000, while the increase in fuel consumption has only been 3%. Planes have been redesigned, engines have become more efficient and in the past ten years we have seen an acceleration in the use of composites as lightweight materials in airplanes.

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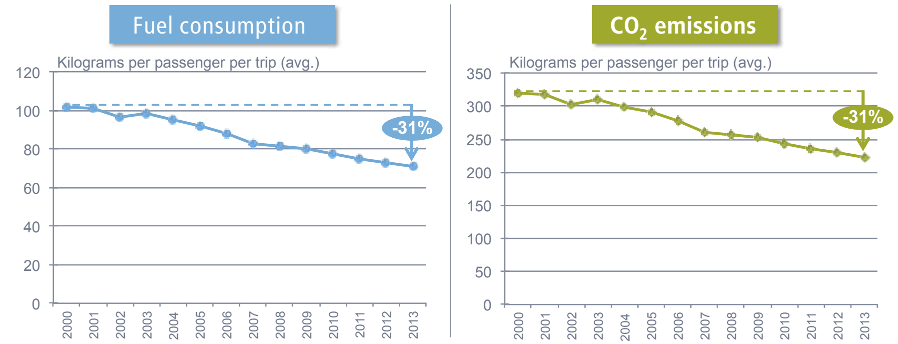

Fuel consumption and CO2 emission in air travel. Source: Airbus CERA.

It is not rocket science: For things to stay as they are, things will have to change. Although this is only a very modest aspiration, it is the least we can do for future generations. And when it comes to polymer engineering, plastics and composites, it means making clever choices on what we have to scale down on, and what we might actually have to scale up.

1. Professorship for Polymer Engineering: its position in Research, Education and Entrepreneurship

The professorship for polymer engineering was founded in 2008 by Windesheim University of Applied Sciences. It was established at the request of the Dutch Chamber of Commerce, which had signalled a future shortage of employees for the manufacturing industry and a gap in knowledge. Since then the team has grown into a group of 16 researchers, both part-time and full-time, a professor, an associate professor and support staff.

The group's objective is to improve the knowledge base on the sustainable processing of plastics and composites within and through the higher education system.

In accordance with Windesheim's principles for a balanced combination of Education, Research and Entrepreneurship, over the course of the years a way of working has been adopted so that each of these components are incorporated into the work of the research group.

1.1 Industry support

At the heart of the research group are six Dutch companies which support the group by contributing both knowledge and finance. They share the belief that the study of plastics should be stimulated in the Dutch higher education system, which should lead to a better curriculum and ultimately result in better-qualified future employees. These partner companies are: Wavin, Philips, Schoeller Allibert, Dyka, Attero and Moba. For composites, the team is supported by the Flevoland initiative: Compoworld. The team is extremely grateful for their support.

2. Applied Research - going the full circle: research, industry's needs and education

Although the Human Capital Agenda weighs heavily on the Professorship's agenda, its primary function is as a research group in Polymer Engineering, delivering output in the field of applied science. The team operates within market-based projects and, currently, comprises lecturers from Civil Engineering, Industrial Product Design and Mechanical Engineering. Depending on the requirements of the project, lecturers can participate from a range of disciplines within Windesheim's Engineering & ICT Educational Division , such as Architecture and Construction Engineering or Industrial Engineering & Management.

To achieve the objective to improve the knowledge base on plastics and composites within the higher education system, the output of the projects is integrated into the curriculum of these study programmes. In this way the curriculum is continuously being updated in line with market trends and needs. The beauty of such a multidisciplinary team is that knowledge harvested from the projects can find its way into at least three study programmes at Windesheim's Engineering & ICT Educational Division. This can be illustrated by the fact that, since the team started working with composites in 2013, lessons have been developed and incorporated into both Civil Engineering (a full course within the Construction Design minor) and the Polymer Product Engineering minor (attended by students from Mechanical Engineering and Industrial Product Design).

The best way for students to directly benefit from the projects conducted as part of the Professorship is, of course, to participate. During 2013, more than 90 students were involved in the execution of the projects either as interns, graduate students, minor students or research assistants.

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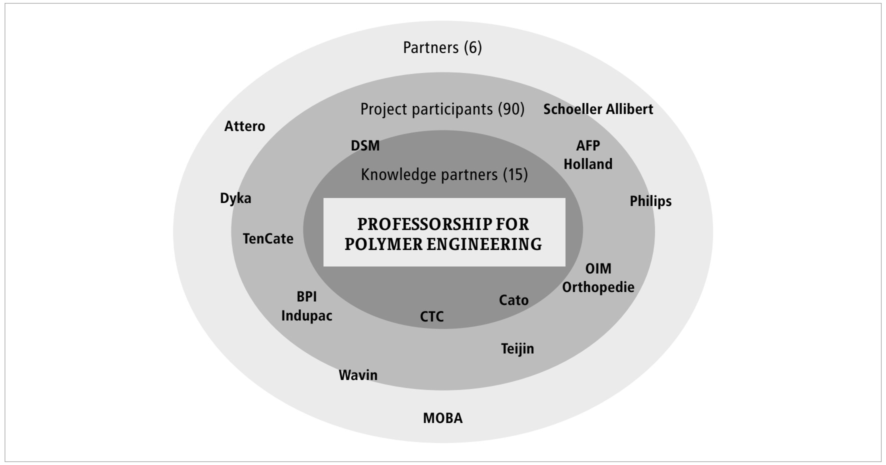
As befits an applied research team, three to twelve regional companies are involved in each project both during the project definition and the execution phases. This results in projects with the involvement of the industrial sector and this further supports and strengthens the innovation power of the region.

To summarize: the team's mission is to improve the knowledge base on plastics and composites within the higher educational system. Applied research will help bridge the knowledge gap between industry and education, and will, therefore, ensure the supply of trained professionals to the plastics industry in the future.



Examples of industry involvement.

2.1 Research programmes

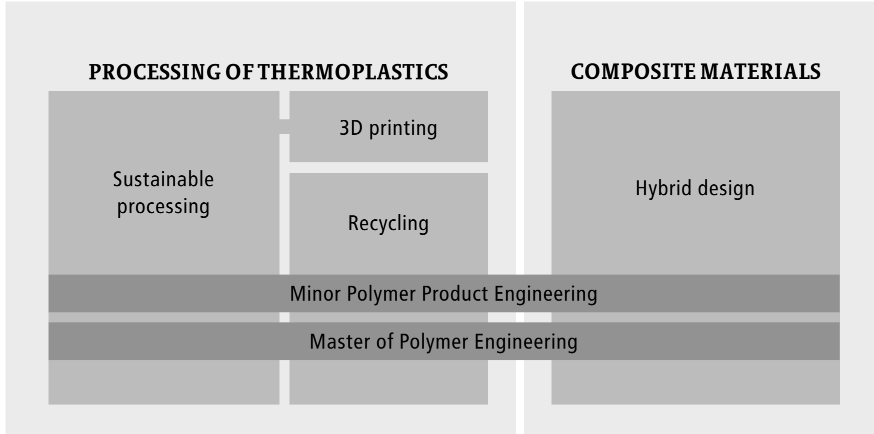
Based on Windesheim's policy of educating "Highly Trained and Socially Engaged Professionals" and, therefore, featuring sustainability high on its agenda, sustainability was a natural choice to umbrella the research programme – sustainability in plastics processing, sustainability in raw materials and durability of materials.

We, therefore, made the choice to pursue two research programmes:

1) processing of thermoplastics, and

2) composite materials.

The thermoplastics processing programme can be divided into sustainable processing, including 3D printing and recycling, and the composite part focuses on hybrid design:



Research Programmes Professorship for Polymer Engineering Windesheim 2015.

Each of these lines will be discussed in more depth later. The 3D Programme is considered part of the Sustainability in Plastics Processing Research Programme because 3D printing is a plastics processing technique and is aimed at cost reduction and smart production of plastic parts.

The group has a current project portfolio of two projects sponsored by SIA RAAK, three sponsored by the Centre of Expertise of TechForFuture and six by the Centre of Expertise of Green PAC. Its total budget is a € 3 million subsidy over the total duration of all the projects.

2.2. Education: involvement at more than one level

As already mentioned, it is the aim of the research group to channel the knowledge gained during the projects back into the educational system.

It was, therefore, a logical step that the Professorship is also responsible for the content of the Polymer Product Engineering minor, which is a multidisciplinary minor focusing on three aspects: material knowledge, processing, and design. Both Industrial Product Design and Mechanical Engineering students attend this minor.

Some of the highlights of this minor are mould design for injection moulding, polymer rheology and the basic principles of plastics processing, but the minor also includes the basic principles of composites and the physical aspects of polymer chemistry. Practical training takes place at several locations, including an industrial environment where the principles of design of experiments are illustrated on injection moulding machines, the Polymer Science Park in Zwolle and Parthian for composites.

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The minor is not only attended by Windesheim students, but also by students from all over the country and sometimes even from beyond Dutch borders. The minor also forms part of a double degree programme with the Hochschule Osnabrück, allowing students to simultaneously obtain a Bachelor of Engineering and a Bachelor of Science.

Quick mould change system for injection Moulding.

Besides teaching Windesheim students, the team's researchers are also involved in the training of teachers at a local vocational college, ROC Deltion, which has also chosen Plastics as a focal point. The lecturers participating in the Professorship's research give master classes to the teachers at Deltion, but, in addition to this training, the opportunity has also been created for some of the Deltion teachers to participate in the projects. The Professorship is also responsible for a Master's degree entitled Master of Polymer Engineering, which is a joint degree with Stenden University of Applied Sciences and the Professorship for Sustainable Plastics.

Industry in the region had expressed a strong wish for a study programme focusing on research into sustainable materials and their processing, allowing the prediction of the behaviour of plastics and composites in an industrial environment and on an industrial scale. The strong ties between Stenden, Windesheim and the regional universities (University of Groningen, Wageningen University and University of Twente in Enschede), has led to a joint degree that employs the university professors' knowledge and expertise and the knowledge input from the Professorships.

This study programme aims to provide a broad knowledge base from a materials, engineering and design point of view and aims to enable professionals, upon completion of the course, to systematically innovate with the necessary background in durability and sustainability issues.

The first set of students started in February 2014.

Associate professor Geert Heideman (Windesheim), professor Rudy Folkersma (Stenden), professor Katja Loos (RUG) and the master students, class of 2014.

2.3. Centres of Expertise and the Polymer Science Park

Whereas in the initial years of the Professorship the team had to go it alone, today there are three initiatives in the periphery of the team that help create an infrastructure of local industry around the team.

The first two are Centres of Expertise. Windesheim's Engineering & ICT Educational Division is linked to two Centres of Expertise. One is entitled Tech For Future[1], which is a collaboration between Saxion University of Applied Sciences and Windesheim. This centre is linked to Topsector High Tech Systems and Materials, which is specifically for the East Netherlands region. The aim of the centre is to further unlock the innovative power of the East Netherlands region through applied research and by providing a link between the collective knowledge and brain power incorporated into the ten Professorships at Saxion and Windesheim as well as that of local industry.

The second Centre of Expertise is Green PAC[2] (Green Polymer Application Centre), which is a joint initiative of Stenden University of Applied Sciences and Windesheim. This centre is linked to Topsector Smart Polymeric Materials. It targets the north-eastern region of the Netherlands and focuses on sus-

[1] TechForFuture.nl

[2] GreenPAC.eu

tainability in plastics, fibres and composites. Not surprisingly, ‘green’ is very much a theme at Green PAC. In this particular centre only the two Professorships on plastics of the two parties, which are Sustainable Plastics at Stenden and Polymer Engineering at Windesheim, are involved. The thing that sets Green PAC apart from other centres of expertise is that, besides applied research, it also provides a growth centre for start-ups (iLab[3]) and scale-up facilities for smaller sized companies (COCI[4]).

And last but not least, the Polymer Science Park[5] located in Zwolle. This Open Innovation Centre has six founding fathers: Windesheim University of Applied Sciences, the vocational college MBO Deltion, the University of Twente, Wavin, DSM and VanWijhe and can boast approximately 35 local companies as its members. This centre offers facility sharing, open innovation and a small-scale industrial environment where industry can meet for small or bigger projects. Not surprisingly, the iLabs, with their young entrepreneurs, have found a home at the Polymer Science Park.

2.4. Plastics Entrepreneurs

This is the latest chapter in the activities of the Professorship and it completes the triangle Research, Education and Entrepreneurship as practised by the Dutch Universities of Applied Sciences.

The first step towards entrepreneurship came when companies that had previously participated in one of the projects became interested in continuing the partnership in follow-up projects and were willing to pay towards the project costs. The second step was the establishment of the Innovation Labs (iLab) at Green PAC, which I mentioned earlier. When the opportunity arose at Green PAC to create an incubator for start-ups with a link to plastics, the iLab was created. It was a logical step to locate this at the Polymer Science Park.

The iLab promotes entrepreneurship in Smart Polymeric Materials. The combination of the Professorship’s knowledge, the practical skills and equipment present at the Polymer Science Park and the coaching by industry professionals or via Kennispoort will, hopefully, not only lead to a higher success rate for start-ups, but also generate a creative buzz around plastics.

[3] greenpac.eu/nl/ilab/
[4] greenpac.eu/nl/coci/
[5] polymersciencepark.nl/

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Since its launch in November 2013, six start-ups have located within the iLab. These include Medical-2Market, DutchFiets, Growcamp and B. Vroegh Design. Their varied use of and interest in plastics are a perfect reflection of the real plastics industry.

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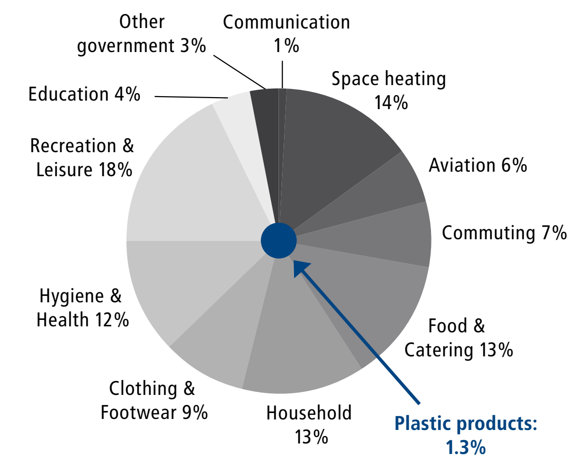
3. Research Programme: Recycling

In 2012 global production of plastics equalled 288 million tonnes. In Europe 57 million tonnes was produced[6], of which 40% was used for packaging. Although these are frightening numbers, plastic products are estimated to represent only 1.3% to 3.6% of the carbon footprint of consumers[7, 8].



Relevance of plastic products in the total carbon footprint of consumers © PlasticsEurope.

[6] Plastics Europe, Plastics- the facts 2013

[7] Plastics Europe, Denkstatt report: The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe, Summary report 2010

[8] Martin Patel and Nitin Mutha 'Plastics Production and Energy', Encyclopedia of Energy, Volume 5, 2004

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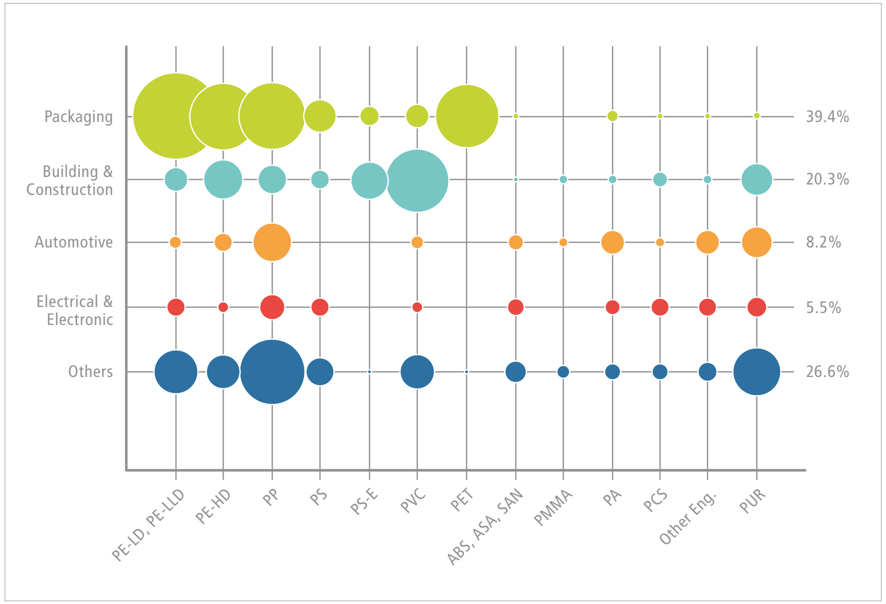
As we all know, the problem with plastics lies not so much in the fact that these materials are man-made and have long-lasting properties, something that is actually desirable but in the fact that plastic objects are produced in mass amounts for the consumer industry and also get disposed of in bulk. On top of that, nature has no natural way of breaking it down so a good strategy is called for when it comes to the waste phase of plastics.

Plastics cannot be recycled in the simple way that glass or paper can be recycled. Glass is fully recyclable – a used bottle can be utilized to manufacture a new bottle – leading to an endless glass recycling cycle in which nothing is lost in terms of both quality and quantity[9]. For plastics this is not possible. The chemical variety is too extensive in that there are countless types and each has its own set of mechanical properties. Add to that the use of additives as performance enhancers plus the effects on the mechanical properties of the various mechanical production steps towards recycling and the scale of the problem becomes even bigger.



European plastics demand by segment and resin type 2012 © PlasticsEurope.

[9] www.verallia.com/en/sustainable-development/glass-recycling

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Of course there are the obvious options for plastic waste, referred to as the waste hierarchy: 1) avoid it; 2) reuse it; 3) substitute it; 4) recycle it; 5) regenerate the energy by incineration[10]; 6) regenerate the energy by reducing the plastic to a fuel like diesel[11]; or, and this is of course the least elegant, 7) landfill.

Because of this sheer variety of plastics, the plastic waste problem is a challenge that is easiest addressed at product level. There are many examples of product cycles where success can be claimed. Examples are PETcore Europe[12] or Reconvinyl[13], which recycle PVC waste and are the operational arm of VinylPlus, the ten-year Voluntary Commitment of the European PVC industry. In 2013, a total of 435,083 tonnes of waste was recycled through Reconvinyl across 16 European countries, with the total Reconvinyl network comprising 141 recycling companies[14].

An important milestone to help increase the recycling rate of plastic has been the 2025 landfill ban for recyclables as announced by the EU Commission in June 2014. The new waste targets for EU members will, hopefully, turn Europe into a more circular economy and not only boost recycling but also profitability. Targets have been set for the recycling of 70% of municipal waste and 80% of packaging waste by 2030 and these include a ban on burying recyclable waste in landfills from 2025. There is also a proposal for the reduction of marine litter. According to EPRO the European Association of Plastics Recycling and Recovery Organisations in 2012 34% of plastics packaging waste was recycled, 35% used for energy recovery and 31% for landfill[15], which surpassed the EU 2012 minimum target of 22.5% for recycling.

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[10] http://www.bpf.co.uk/Recycling/Position_Statements/Incineration_and_Energy_Recovery.aspx; Retrieving and converting energy from polymers: deployable technologies and emerging concepts Bilge Baytekin,a H. Tarik Baytekina and Bartosz A. Grzybowski, Energy Environ. Sci., 2013,6, 3467-3482; Nate Seltenrich, http://e360.yale.edu/feature/incineration_versus_recycling__in_europe_a_debate_over_trash/2686/

[11] www.petrogas.nl; www.diesoil.ch; www.cynarplc.com, e-n-ergy.com, www.envion.com, polymerenergy.com; www.polygreen.com.ph; www.plastic2oil.com, www.greenworldystems.nl; Brajendra K. Sharma, Bryan R. Moser, Karl E. Vermillion, Kenneth M. Doll, Nandakishore Rajagopalan. Production, characterization and fuel properties of alternative diesel fuel from pyrolysis of waste plastic grocery bags. Fuel Processing Technology, 2014; 122: 79

[12] petcore.org

[13] recovinyl.com

[14] PVC Recycling Rates in Europe Improved under Reconvinyl; 435K Tons Recycled in 2013, SpecialChem June 23, 2014

[15] http://www.epro-plasticsrecycling.org/pages/75/epro_statistics

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Recycling of plastics started in the Netherlands[16] with the recycling of post-production waste at companies such as Morssinkhof Lichtenvoorde (Europe's biggest recycling company with an estimated 150 kta industrial recycling polymers), AKG, and Cumapol Emmen. The trend at moulders (companies that produce plastic parts) to incorporate their own post-production waste into the production cycle, has led to recycling companies including post-consumer waste into their recycling streams for the production of recycle-grinds. In addition, post-consumer plastics are reclaimed from household waste by companies such as Omrin and Attero, or sorted by companies such as Sita.

A couple of years ago, the organisation Nedvang *(Nederland van Afval naar Grondstof)* started the campaign "Plastic Heroes" to increase consumer awareness of plastics and to improve recycling rates. Nedvang learned from the experience of the German, Belgian, Austrian, French, Spanish and Italian recycling efforts over the past 20 years. Using the German sorting and recycling companies and copying the German system[17, 18], the Netherlands made a leap forward in its recycling performance and the recycling of 25kta of plastic bottles with refundable deposits by companies like Morssinkhof, Wellman, Cumapol and 4PETrecycling certainly added to the progress. We can add to this the experience Dutch companies, such as Morssinkhof, Wellman, Cumapol and 4PETrecycling, already had recycling 25 kta of plastic bottles with refundable deposits. Nedvang can currently proudly report more than a 100kton/a of post-consumer plastic recycling.

In short, waste management has become crucial when trying to close the plastic loop. One such initiative is the Plastic Cycle Value Chain Agreement (*Kunststof Keten Akkoord*)[19], from the Ministry of Infrastructure and the Environment, which in 2013 was signed by 80 companies, knowledge institutes and port authorities, including the Professorship for Polymer Engineering.

The idea behind the agreement is to work together in the value chain to try and close the plastic cycle. The aim is to close the plastic cycle as much as possible by sustainability in the production processes, by product engineering and design focussing on widespread reuse and by collecting and sorting plastic waste streams in an environmental-friendly way. Furthermore, the basic principle is

[16] Interviews with Nijkamp Consultancy

[17] http://www.dkr.de/downloads/spezifikationen.html

[18] http://www.nedvang.nl/sites/default/files/downloads/20140703_-_vergoedingen_kunststof.pdf

[19] Plastic Cycle Value Chain Agreement,
http://kunststofkringloop.nl/wp-content/uploads/2014/05/Ketenakkoord-Kunststofkringloop-EN.pdf

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that all of this will improve the competitive position of the Netherlands, as stated in the green growth programme's objective.

There is, however, one legislative fly in the ointment of all enthusiastic recycling initiatives: REACh. REACh is the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals within the European Union. Its main aim is to ensure a high level of protection of human health and of the environment from the risks posed by chemicals. REACh has, therefore, made the industry responsible for assessing and managing the risks posed by chemicals and for providing appropriate safety information to its users.

Under REACh, recycling companies selling recycle-grinds have become raw material suppliers and have, therefore, the same obligation as all other raw material suppliers under REACh. In a way this is logical because, after all, you are responsible for what you sell. The issue is that under REACh these materials have previously been approved to be sold in or imported into the European Union and it is impossible for the recycling companies to trace the origin of every tiny bit of scrap, particularly when it comes into their plants in ktons at a time.

This is a major issue that the EU will have to resolve[20], because to not recycle plastic waste is not a sustainable option.

3.1 Focus on: how to facilitate recycling

In today's society we have come to accept that as a company, knowledge institute or individual we have a duty to assess our sustainability and improve on our carbon or eco footprint. For this research team this means that sustainability is part of all the activities we are involved in. The Sustainability in Plastics Processing research programme was born from that idea, although end-of-life recycling and the recyclability of plastic parts are at least as important.

There are several recycling companies located within the same region as Windesheim. Examples are Attero, which is a partner company to the Professorship and active in plastic recycling, and AKG, which is plastic specific. Over the course of the years many Mechanical Engineering students have had the opportunity to carry out internships related to the machinery in the AKG recycling plant.

Recycling itself, as in 'the mechanical steps leading to recycling and the effects on the (mechanical)

[20] http://www.plasticsrecyclers.eu/reach-plastics-recyclers

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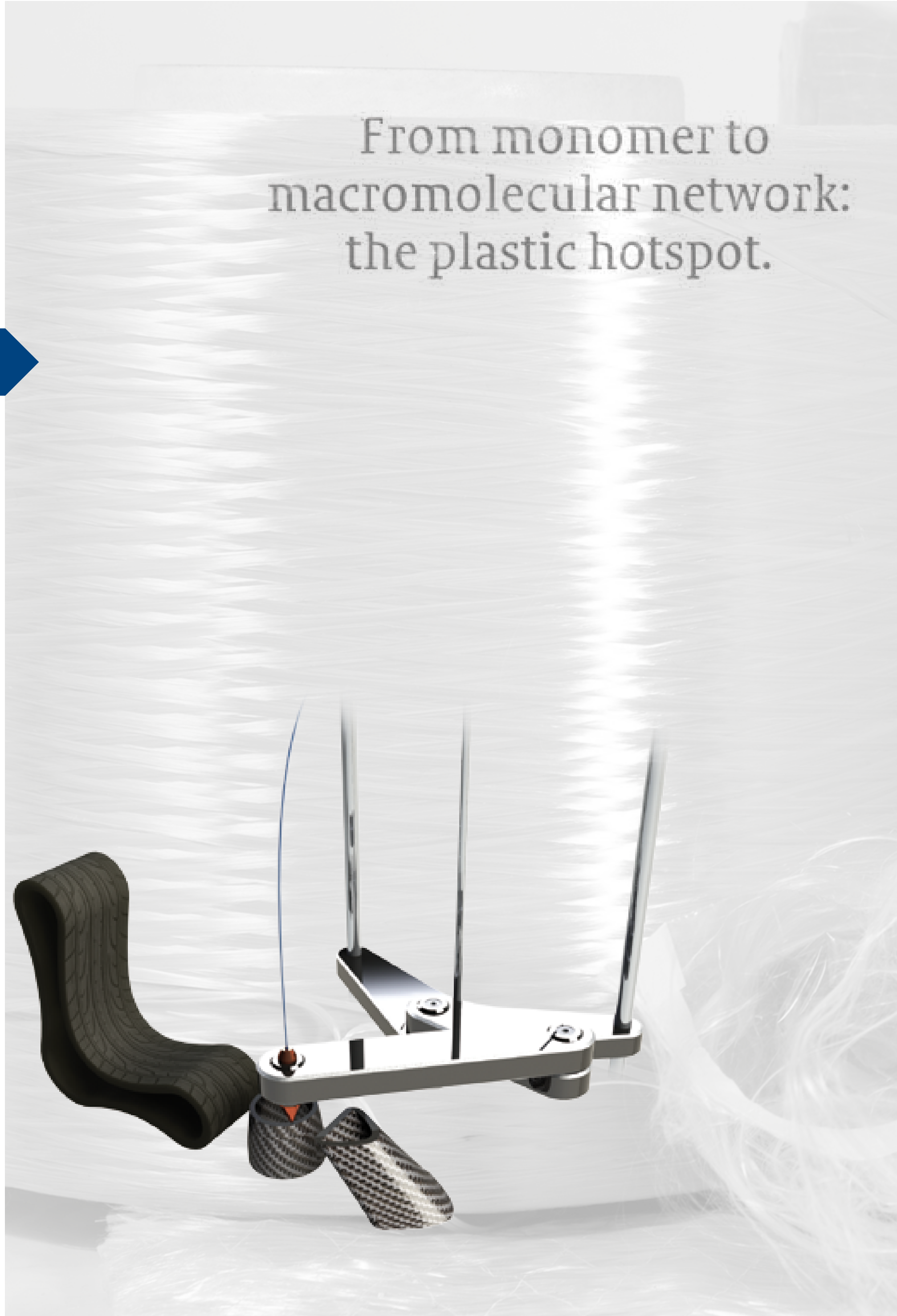


properties of the material' was, therefore, chosen as one of the focal points.

The other focal point of the team's recycling efforts lies very much within the design of products suitable for recycling. There is a clear need to teach students to think beyond the user phase of the products they design, so products of the future can either be easily disassembled and recycled separately or be designed with the lowest number of different plastics possible.

These two statements combined led to the following mission statement of the team on recycling: 'to generate insight into the effects of use, design and recycling on the future possibilities of plastics'. Future projects on recycling will be chosen based on this mission statement.

3.2 Past and present activities in recycling

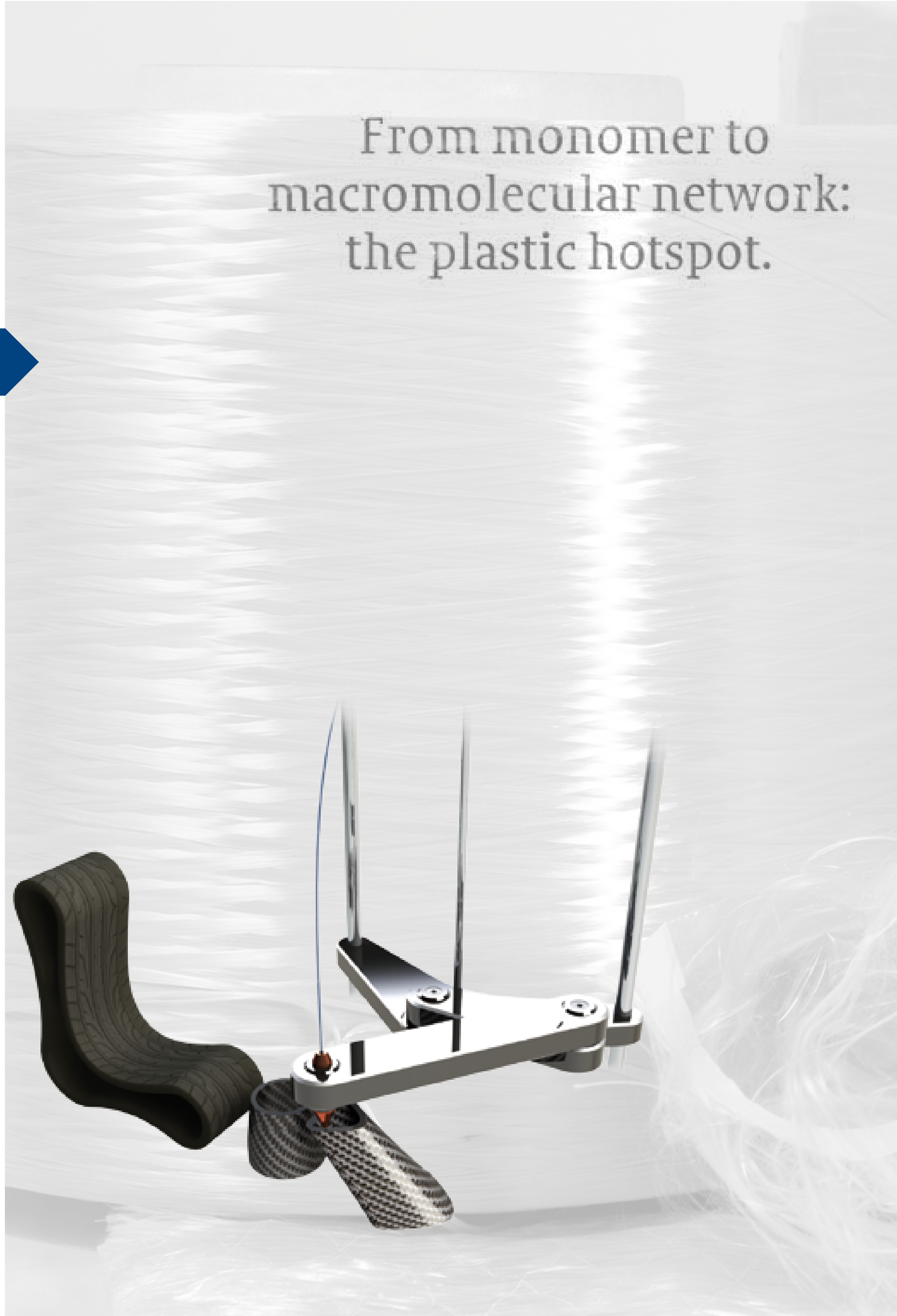
Together with the Research Centre for Design and Technology of Saxion University of Applied Sciences, a SIA RAAK subsidized project entitled Recycling in Ontwerp (Recycling in Design)[22] was carried out. This project was finalised in 2013. At the core of this project was the desire for every engineer to be able to design multicomponent products in such a way that disassembly would allow for easy recycling of the separate parts once that product has reached its end phase.

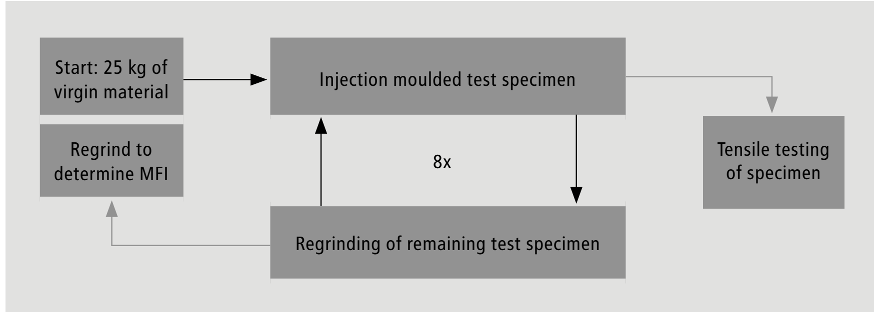
One of the topics within Windesheim's part of the project, therefore, focused on design methodologies for easy recycling, such as how to join materials, how to choose materials and how to take advantage of modular design. The second component of Windesheim's part of the project focused on a basic understanding of the evolvement of the mechanical characteristics of plastics upon recycling by compounding and regranulating plastic seven times after processing (injection moulding) for the plastics PP, HDPE, PA6 and ABS and in conjunction with AKG upon ten times recycling of PP in an industrial way[22].

"Project Recycling in Design": 8 generations of recycling of HDPE.

[21] www.recyclinginontwerp.com

[22] Kunststof Magazine, nummer 1, Januari 2014, pagina 32-34, Hermans, Boks en Van Dijk





Project “Recycling in Design”: Labscale simulated recycling.

Some of the conclusions were that for PP the molecular weight started to drop after generation 3, whereas during recycling of PE a decrease in MFI was found indicating crosslink formation. The industrial effects as measured for PP in mechanical properties showed the same trends compared to the labscale simulation.

3.2.1 Coating on Plastics

To build on the first successes, a follow-up project was set up together with Saxion University of Applied Sciences, entitled “Recycling of Polymeric Materials”. This time subsidized by the Centre of Expertise HTSM TechForFuture. The set of seven times recycled materials was extended with amongst others PET and PS. The effects on recycling of artificial grass were studied, but it was also investigated if it was possible to powder coat recycled plastics to enhance consumer acceptance of these mostly dark coloured materials without the use of primers, solvents or other pre-treatments. Together with DSM Powder Coating Resins, Maan (gas plasma treatments), the IR heated powder coating line as present at the Polymer Science Park and the use of cheap conductive fillers, it appeared to be possible to reach adhesion of the applied coating of 480 psi.

Project “Recycling of Polymeric Materials”: Adhesion and Gitterschnitt tests on powder-coated PP test panels.

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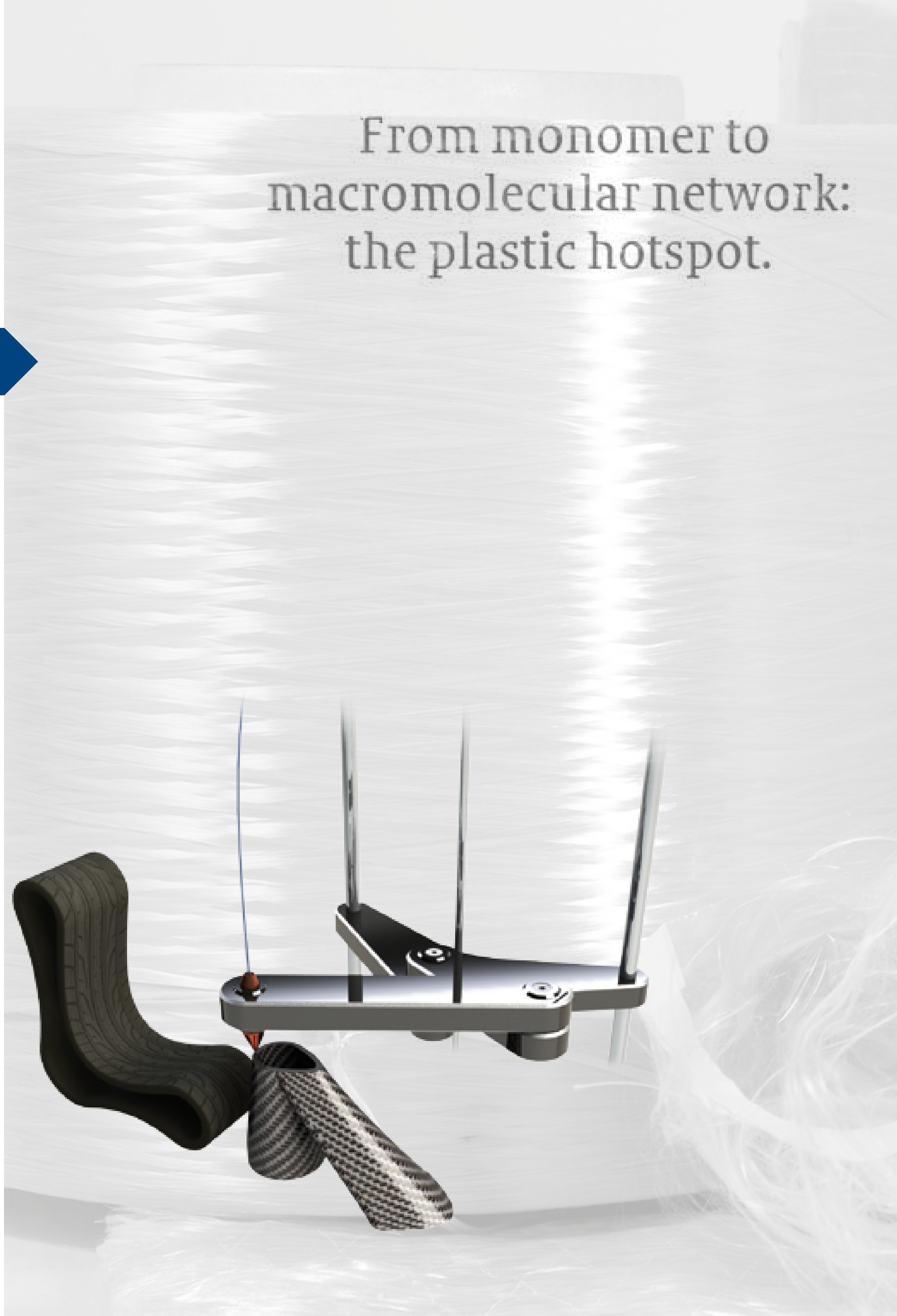
At the Centre of Expertise of Green PAC, a third project was set up with Stenden University of Applied Sciences and the Professorship for Sustainable Plastics (Duurzame Kunststoffen). The main focus of this project lies in PET recycling, e.g. the application of rPET in filaments for FDM printing, in carpet yarn and in thermoplastic composites.



4. Research Programme: Sustainability in Plastics Processing

Part of this chapter was first published as chapter 1 in the end report of the project KOENST.

As soon as people think about the sustainable processing of plastics, the word ‘green’ comes to mind conjuring up images of biobased plastics. But is that the way forward? Is mass production with optimized production methods not another efficient way to get the most out of our precious resources? As defined in the Plastic Cycle Value Chain Agreement, sustainability in the production processes is equally valuable.

Examples of European projects on energy efficiency in the plastics processing industry are RECIPE[23] (Reduced Energy Consumption in Plastic Engineering) and EUPLASTVOLTAGE[24] (European Plastics Converting Industry Voluntary Long-Term Agreement on Energy Efficiency), the latter resulting in the voluntary agreement of the EuPC[25] (European Plastics Converters) to a 20% reduction in energy use in the industry by 2020. However, at national level the Dutch government and industry signed an agreement called MJA-3[26] (*Meer Jaren Afspraak*), which targets 30% energy reduction in 2020.
Because the industry cannot achieve such targets independently, efforts are also being made by the machinery manufacturers. It was announced in 2014 that EUROMAP, the umbrella association for plastics and rubber machinery manufacturers, has introduced a voluntary energy label for plastics and rubber machinery[27] to provide the plastics processing industry with transparent energy efficiency

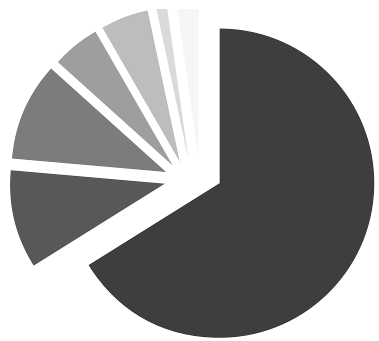
[23] http://ec.europa.eu/energy/intelligent/projects/en/projects/recipe#results
[24] http://ec.europa.eu/energy/intelligent/projects/en/projects/euplastvoltage
[25] http://www.plasticsconverters.eu/
[26] http://www.rvo.nl/subsidies-regelingen/meerjarenafspraken-energie-efficiency
[27] www.euromap.org,
http://www.euromap.org/files/PR_2014%2008%2018_EUROMAP_90_Energy%20efficiency%20label.pdf

classes and to allow customers to make comparisons. This is similar to the way in which energy labels work in relation to household equipment or houses. In addition, the association has published energy measurement standards for injection moulding and extrusion blow moulding machines.

4.1. Breakdown of an Energy Policy

Energy consumption constitutes about 10% of the costs within the plastics processing industry, which is the third main cost[28] after material and labour. The main energy uses and costs are related to machinery and services (92%). Lighting, heating and offices are minor contributions to costs (8%). Due to the continuing increase of energy prices and the desire to reduce greenhouse gas emissions, saving energy has become even more important. Basic techniques to reduce energy use are simple and easily applied and savings of 30% and even greater have been reported. With the right focus by industry on reducing energy consumption, the goal of a 30% reduction of energy in the MJA-3 covenant can be considered feasible. Within the covenant, companies are obliged to develop an Energy Saving Plan (EEP) every four years and are required to report on progress and implementation annually.

When assessing the energy use and possible improvements in a production plant, a distinction can be made between de various stages in energy policy: energy awareness, energy management, process optimization and process innovation. Each of these will be explained in the following sections.



Energy cost distribution for plastic processing, taken with permission from R.Kent 2008 Energy Management in Plastic Processing.

[28] Kent, R. (2008) Energy Management in Plastic Processing

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4.1.1 Energy awareness

One of the least monitored costs in the industry is apparently energy use[29]. In the first SIA RAAK subsidized project of the team for Sustainable Processing[30], an energy scan (NRG Scope) was developed allowing plastics processing companies to compare their energy use with similar production facilities. Based on this scan the possibilities to reduce energy use can be mapped, and all the industrial partners in the project used this scan to gain insight into their energy use. The scan focuses on the use of energy for lighting, heating, offices and transport. The outcome of the scan can, for example, result in a recommendation to automatically switch-off computers or to use led lighting instead of light bulbs, etc. Although these costs only represent 8% of the total energy consumption, it is important to map these costs in order to increase awareness among personnel and to stimulate motivation for improvements in the total production process.

4.1.2 Energy management

Besides the actual processing, heating and cooling of plastics, a lot of energy flows into utilities such as water pumps, hydraulics, chillers, compressed air and conveyer belts. These costs mainly go unnoticed, although with good energy management these costs can easily be reduced, for example by switching off the conveyer belts when there are stoppages in the processing machine. The implementation of variable speed drives can also contribute to energy savings in the case of dynamic process conditions and many more examples can be found[31]. Proper maintenance also plays a part and will keep these utilities in optimal condition with minimized energy consumption. The energy consumption of all utilities has to be measured individually and compared to machine data sheets, while discrepancies from normal operations should spur management into action. When these signals are not ignored, energy management can successfully lead to energy savings and, hence, more profit.

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[29] http://www.greentechmedia.com/articles/read/the-50-kilowatt-initiative

[30] Boks, N. and Dijk, T. van (2011) Meer producten, minder energie (duurzaam produceren in de kunststofindustrie), Windesheimreeks kennis en onderzoek

[31] Kent, R. (2008) Energy Management in Plastic Processing

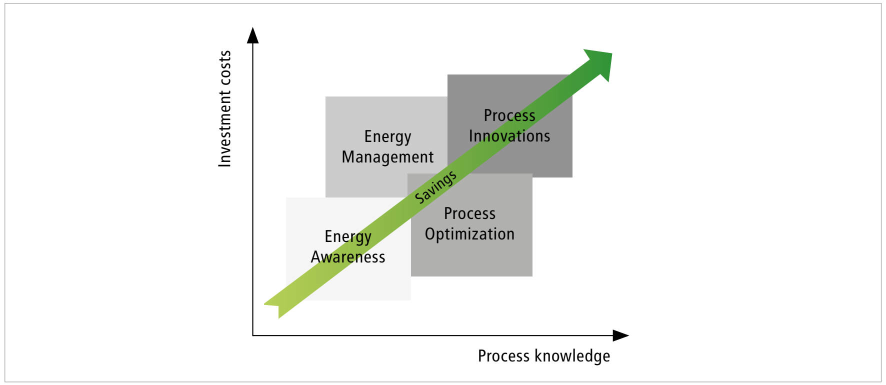
[32] Project euRECIPE, http://ec.europa.eu/energy/intelligent/projects/en/projects/recipe, “Low Energy Plastics Processing, European Best Practice Guide”, for example page 18, fig 4.2 ‘typical example of energy consumption in an injection moulding plant’

4.1.3 Process optimization

The main part (~60-66%) of energy consumption is due to the processing of the plastic[32], which involves melting the granules and solidifying the product. In the project mentioned earlier a process parameter effect method (PEM) was developed[33], which offers a practical approach to gaining insight into the effects of process parameters on product characteristics such as weight, dimensions, energy consumption and use of additives. For example, minimizing the weight of a product will reduce the amount of material to be melted and this, in turn, reduces energy use. This method has been successfully applied to injection moulding, extrusion, sheet moulding and blow moulding. Depending on the production method the average material weight savings were found to be 2.6%, while energy use could be reduced by 6.7%. Alternatively, cost savings could be achieved by reducing additives, for example the amount of dye. It was found that a reduction of 35% in added dye resulted in products of acceptably good quality. It was also found that the highest savings in energy could be achieved in sheet and compression moulding due to the enormous amount of air needed for cooling and compression.

4.1.4 Process innovation

The various stages of an energy policy[34] can be represented by different levels of investment costs and knowledge of the production processes, as outlined in the graph below, with the darker green representing higher potential for sustainable improvements. The investment costs are highest for pro-



Project "KOENST": Stages of energy policy, taken from [J.Buist, et al. 2015 Renewable energy-efficient plastics production technologies].

[33] Boks, N. (2011) Procesparameter Effect Methode (Handleiding), Windesheimreeks kennis en onderzoek

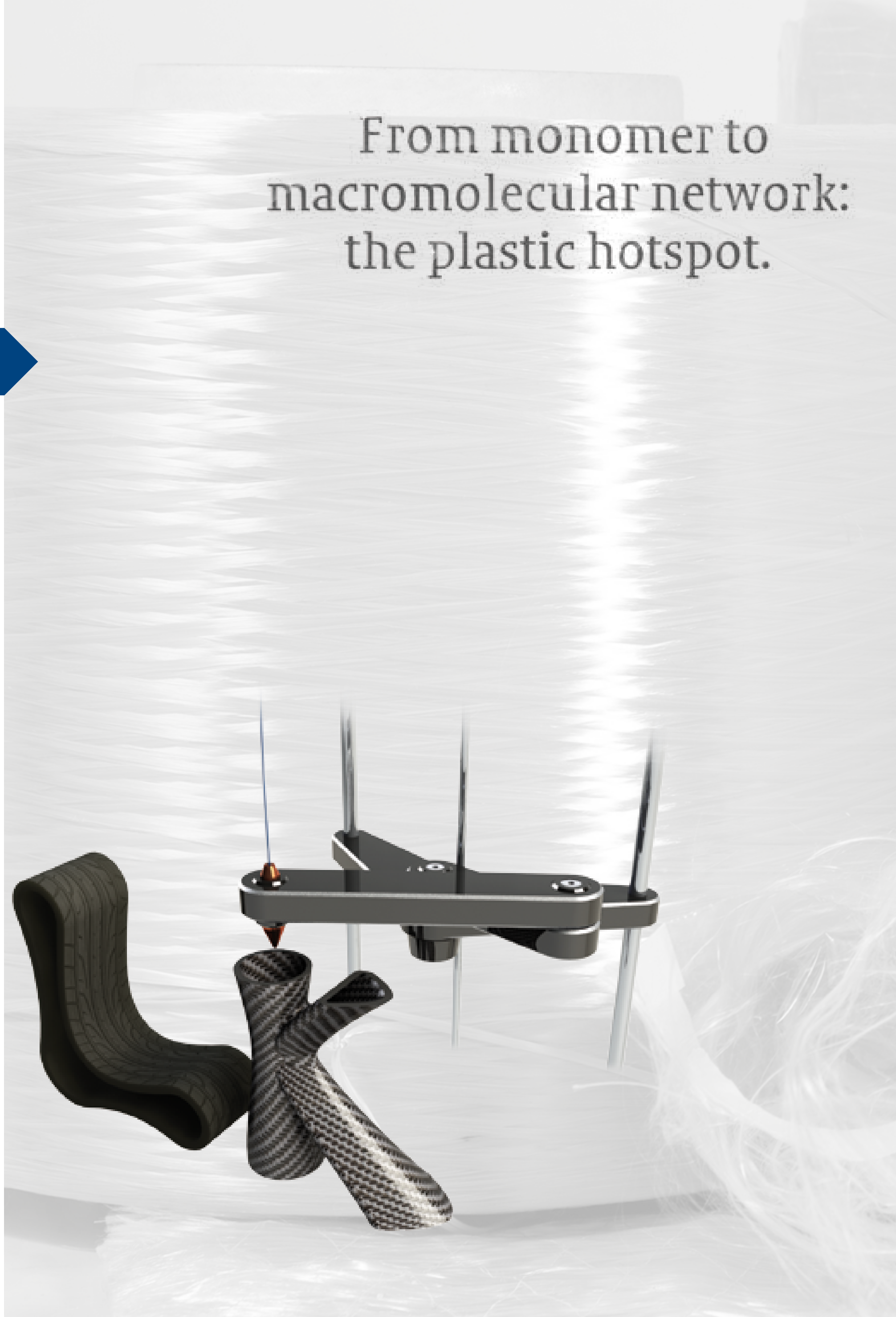
[34] Buist, J. (2015) Renewable energy-efficient plastics production technologies, Windesheimreeks, to be published

cess innovations due to research and development costs on top of purchasing, implementation and testing of new equipment. At the other end of the spectrum production processes can be optimized by a simple change in the settings of the machines with little investment in machinery, although a thorough understanding of the physics of the processes is needed. It can be concluded that to save the largest amount in energy costs a thorough knowledge of the production processes is needed. Innovations in the production process are necessary to adjust to the rapidly changing markets and the competitive field. In addition to this, the transition to sustainable energy sources, such as biomass and geothermal heat pumps, triggered the development and implementation of new processing equipment. For example, with geothermal heat, plastics granules can be preheated before being fed into the processing machines. Of course, the same can be achieved with residual heat due to the cooling and solidification of the material in the mould. Solutions, however, still have to be found on how to prevent the plastic granules from sticking to each other during transport to the machine and in relation to the effects of contaminated cooling air on the ultimate product quality, for instance with paraffin wax in the sheet moulding process.

4.2 Focus on: tools that help speed up production innovation

The one thing that can be said of almost every modern-day challenge is that the more you work together, the more you can achieve. To help the plastics processing industry meet their targets, the machine manufacturers need to play their part, although knowledge institutes can also play a part.
The region around Windesheim has a strong manufacturing industry. This, combined with the fact that Windesheim has chosen sustainability as one of its core values and that most of the roots of the team are in Mechanical Engineering has resulted in the team choosing to focus on sustainable processing and recycling above biobased materials. This is because, locally, real steps can be made towards meeting these energy goals.
This led to the following mission statement of the team on Sustainability in Plastic Processing: ‘The development of tools for the plastics processing industry that will speed up innovation in production methods leading to lower costs’. This mission statement will serve as the filter to choose the future project pipeline of this research programme.

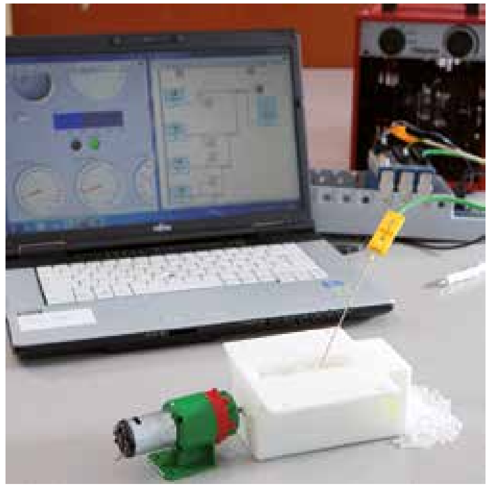
[35] Based on an idea of prof. Dr.-Ing Wortberg Journal of Plastics Technology 6 (2010) 2



4.3 Past and present activities in Sustainability in Plastics Processing

The first project that was carried out within the Professorship for Polymer Engineering was the already mentioned SIA RAAK sponsored project on Sustainable Plastics Processing *(Duurzaam produceren in de kunststofindustrie)*. This project was nominated for a RAAK award and a tool was developed entitled the Windesheim Energy Efficiency Index. This project studied reduction in energy use as well as sustainable processing by reducing raw materials.

Continuing the programme line on sustainable processing, this project was succeeded by a RAAK International project concerning sustainable energy use within the plastics processing industry entitled KOENST. This programme aimed at a 10% reduction in energy and one of the results was the design and development of a prototype[35] for plasticizing granulate not using an electricity heated but a gas heated system for extruders or injection moulding machines. This prototype was optimized with respect to manufacturability and the energy efficiency and the reduction of thermal stresses were improved by using numerical simulations. A functional test was carried out with respect to performance, allowable temperatures and thermal stress levels with water, which was followed by



Project "Koenst": Process control for fluidized bed.

[36] Kunii, D. and Levenspiel, O. (1991) Fluidization Engineering, Butterworth – Heinemann series in chemical engineering, ISBN 0-409-90233-0

From monomer to macromolecular network: the plastic hotspot.

long-term tests at 200°C with thermal oil. During this long-term test different heat-up and cool-down profiles were generated to show the quick response time of the system, which is an important advantage with respect to electrical heating.

A second prototype developed in this project was a preheating system for granulate by residual heat elsewhere in a production plant. The objective of this research was to develop a uniform flow of hot air into a bed of granules in such a way that the heat exchange is optimized and a temperature gradient is installed. The optimization of the air flow was carried out based on numerical simulations and validated in a laboratory prototype of an incipiently fluidized bed or a bed at minimum fluidization[36]. With the design of the gas heated burner system and the preheating system for granulate showing real promise, a third project was set up (financed by Green PAC) to build on the success of these prototypes. An added angle to this project will be that mixing, temperature and viscoelastic behaviour of elastomeric compounds in an extruder will be measured and simulated to control the 'die-swell' using numerical tools like FEM and CFD.

5. Research Programme: 3D printing

5.1 The next industrial revolution?

At the beginning of the nineties, computer software packages for digital drawing started to replace the drawing tables for good and 3D drawing became state of the art. This revolution tremendously increased the complexity with which products could be designed, hence creating a need for prototyping during the design and development phase. The first Rapid Prototyping techniques were born, but the prototypes were costly and very fragile. The need for actual prototypes became so big that new techniques were quickly developed, lowering the cost per product and improving the quality.

The advantages of 3D printing are big for the plastics processing industry in that products can be produced from a single digital file and without the need for expensive moulds. 3D printing offers a short 'time-to-market', the possibility to produce 'just in time', 'mass-customization' but, most importantly, it offers new design possibilities: additive manufacturing (AM) offers the possibility to create products that are not bound by the physical rules of subtractive manufacturing.

What could be the implications of this revolution? What are these implications in relation to, for example, copyright versus open source designs, intellectual property rights, consumer safety or the production of unsafe or dangerous goods? How fast will it all go? Can we predict what will happen to global logistics[37, 38]? And this is just in the field of plastics. If we venture into the world of cell printing, how will this impact the ethical discussion?

[37] Op weg naar een nieuwe industriële revolutie? De Wereld van 3D-printen, Willem Vermeend, www.3dprintwereld.com

[38] Three dimensional Policy, Big Innovation Centre, October 2012, http://biginnovationcentre.com/Assets/Docs/Reports/3D%20printing%20paper_FINAL_15%20Oct.pdf

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McKinsey has named 3D printing in its hotlist of twelve disruptive technologies that will influence the future[39], although they ranked it ninth in terms of economic impact concluding it will take years before an economic impact will be felt beyond a limited range of goods.
3D printing is a hot topic. It has been a long time since a plastics processing method has created so much interest equally among the general public and the professionals. The advances of the technique in the past couple of years has sparked a curiosity as to what it might bring to individuals and to commercial users. With cost price under constant pressure, any shortcut in lengthy production processes or expensive stock maintenance is a welcomed one. It is not surprising, therefore, that the number of 3D print tradeshows has risen exponentially in the past couple of years[40, 41, 42, 43, 44, 45].

The Dutch government has outlined its ideas to keep the Dutch manufacturing industry at a competitive level in the document entitled Smart Industry[46]. In it, they pinpoint 3D printing as one way to keep the industry strong. This is due to the strong ICT base present in the Netherlands combined with a broad manufacturing industry. Similarly, the Ministry of Economic Affairs commissioned a study into 3D printing to uncover the potential for Amsterdam as a creative city[47].

To make it all happen though, people have realised that we need to work together along the value chain and that government and industry should not only cultivate the necessary conditions but should also provide the right guidelines for this to happen. Against this backdrop, the industry and trade association 3Din.nl[48] was born.

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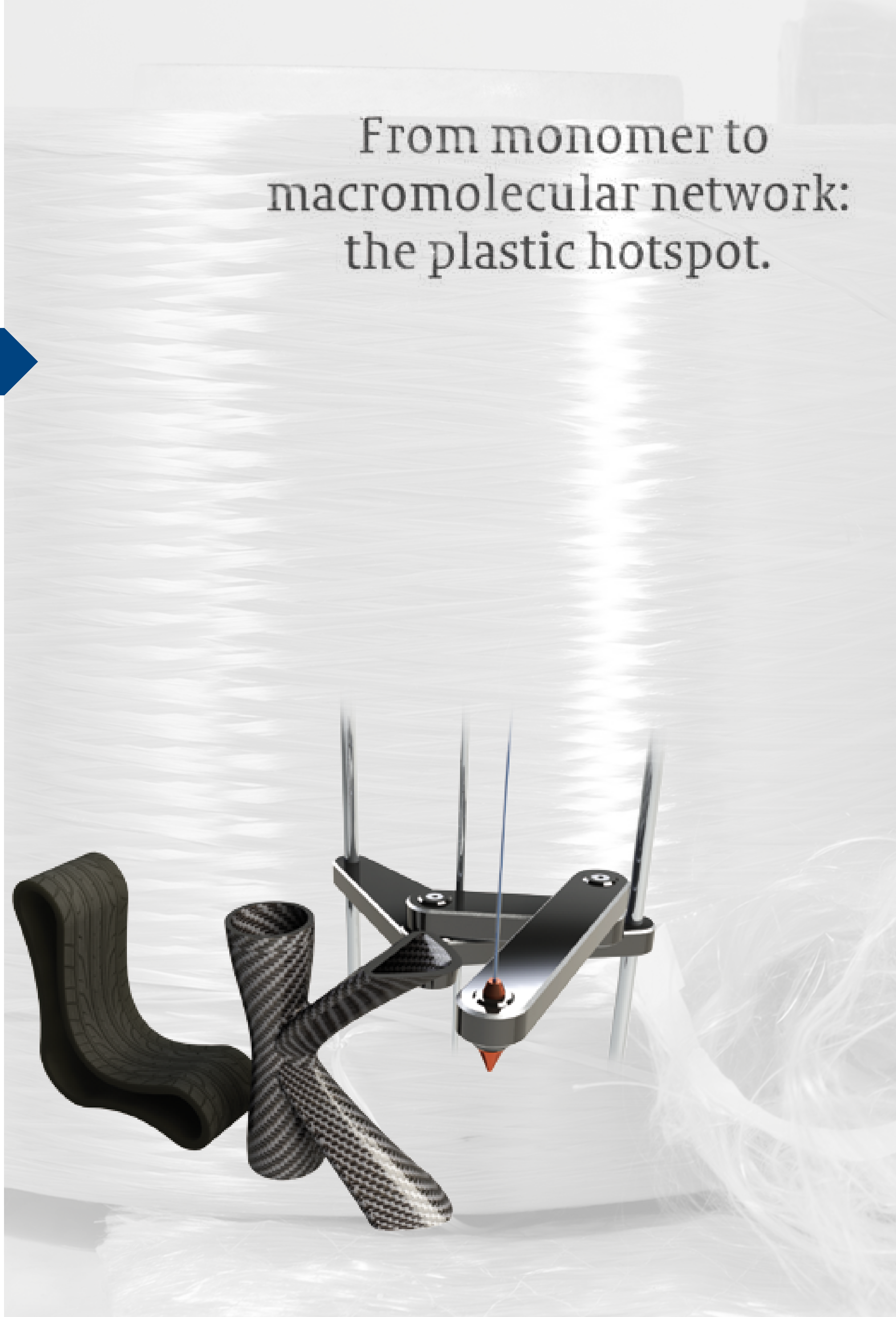
[39] http://www.mckinsey.com/insights/business_technology/disruptive_technologies,
file:///C:/Users/mt0058674/Downloads/MGI_Disruptive_technologies_Full_report_May2013.pdf
[40] rapidpro.nl
[41] 3Dprinteu.nl
[43] 3dprintshow.com
[43] euromold.com
[44] 3dprintingevent.com
[45] inside3dprinting.com
[46] file:///C:/Users/mt0058674/Downloads/smart-industry-dutch-industry-fit-for-the-future.pdf
[47] http://3din.nl/wp-content/uploads/2014/02/ONDERZOEK-GROUND3D-Marktorientatie-3D-printen.pdf
[48] 3din.nl



Not surprisingly, quite a number of centres specializing in 3D printing have sprung up. To name a few in the Netherlands: fablab Maastricht[49] and Arnhem, 3D-HUB at the Chemelot campus[50], Innofabriek[51], 3D kenniscentrum.nl, the High Tech Campus at Eindhoven University of Technology[52] and the city of Rotterdam which has put itself on the map as "The printing city"[53] with its 3D printing academy[54]. At the Universities of Applied Sciences, several research groups have specialized in materials for 3D printing. Examples are the Stenden Professorship for Sustainable Plastics"[55] and the Saxion Centre for Design and Technology[56], where several Professorships specialize in the fine art of 3D printing for materials other than plastics. Then there is Fontys, which recently opened its ObjeXlab[57] or the Rotterdam Professorship for Transition Management, which studied the effects and opportunities of 3D printing on the logistics of Rotterdam port[58].

3D FDM printing.

[49] fablabmaastricht.nl
[50] 3D-HUB@liof.nl,
http://www.dpivaluecentre.nl/inspiratie/projects/onderzoekslab-3d-printen-geopend-op-chemelot-campus/
[51] Innofabriek.nl
[52] hightechcampus.com
[53] printingthecity.nl
[54] 3dprintingacademy.nl
[55] stenden.com/nl/bedrijven/lectoraten/duurzame-kunststoffen
[56] saxion.nl/designentechnologie
[57] ObjeXlab.com
[58] www.vervoerslogistiekewerkdagen.org/docs/over/pers/2.pdf,
http://ecp.nl/bijlagen/4161/presentatie-d-kees-machielse.pdf

5.2 Focus on: functionality translation, knowledge sharing and opening up of new markets

As already mentioned, one of the unique things about 3D printing as a plastics processing method is the connection between the virtual world and the real world. This is something that, on the one hand, can create legal issues, whilst, on the other hand, can accelerate advances in the technique.

Two things happen when the internet comes into play. Firstly, knowledge is shared about the technical aspects, and, secondly, the engineering work is shared by posting the digital files on the web. A thousand brains are always better than one and this becomes even more apparent when facilities are also shared in, for example, the Fablabs and open innovation centres. However, the need to understand the technique in order to be able to take advantage of it in a modern production environment, means a lot of ground work has to be carried out before certain guidelines can be established. Reasons for this are that every object has different dimensions and every object has different material and mechanical requirements. On top of that, the advantage of additive manufacturing over the old subtractive manufacturing combined with standard processing means the final object can be a translation of its functionality rather than the original shape.

At the moment, speed of printing is an issue that needs to be solved for small series production. Another pressing problem, though, is that high performance plastic objects cannot be made because pressure resistance, air tightness and wear are real issues. The industry is, of course, already working on this next step in the further development of the technique and, hopefully, it will come up with new printers and new materials in the near future. Historically the Professorship has contributed to both knowledge sharing and engineering towards functionality. With its roots in Industrial Product Design and Mechanical Engineering, its mission became the creation and dissemination of knowledge on 3D printing. This was achieved through the engineering work carried out for individual cases aimed at finding the specific advantage that 3D printing can offer. The ultimate dream, however, is to help open up new markets by working on the constraints of the technique. The future pipeline of this research programme will therefore consist of projects on co-engineering to enable functionality translation and knowledge sharing but also to help the industry make the next step.

[59] Printen in de *derde* dimensie, Masja Mooij 2014

From monomer to macromolecular network: the plastic hotspot.

Project "Manufacturing Industry Creates New Designs and Possibilities with Rapid Manufacturing": cooling spirals Dyka.

5.3 Past and present activities in 3D printing

The team's first 3D printing project was a SIA RAAK sponsored project entitled Manufacturing Industry Creates New Designs and Possibilities with Rapid Manufacturing *(Maakindustrie creëert met Rapid Manufacturing nieuwe ontwerpen en mogelijkheden)*[59].

The specific advantages of 3D printing were investigated based on 12 case studies for 12 SMEs. Probably one of the best examples of translated functionality was the case of the cooling spiral for partner company Dyka. In this case, the real advantages of additive over subtractive resulted in completely new designs allowing more efficient fluids flow. A second project was set up, again with Saxion University of Applied Sciences, entitled "Breakthrough in 3D Printing", which is subsidized this time by the Centre of Expertise HTSM TechForFuture. The topic of Windesheim's part of the project is to create customization for medical applications such as orthodontics and orthopaedics and to create mechanical simulations of 3D models.

A third project was set up with Stenden University of Applied Sciences, entitled 'Development of new materials and applications for 3D-printing', which is subsidized by the Centre of Expertise Smart Polymeric Materials Green PAC. The aim of this project is to develop new materials and technologies based on FDM in order to increase the industrial applicability of the technique.

6. Research Programme: Composites, Hybrid Design and LCAs

6.1 Cleaner technologies

The composites world has seen more signs of change in the past 10 years than in the previous 40 years. The plus side of the economic crisis has been that the natural demarcation lines between the traditional markets started to blur with everybody wanting a piece of somebody else's market. A shrinking market causes that kind of competiveness, although there is also the pull by the scarcity of oil and, in addition to that, a general drive towards cleaner technologies and further automation in order to professionalise the workplaces and cut costs.

In the field of styrenated unsaturated polyesters, which represents the bulk of the composites industry, the trend for cleaner technologies sparked the development of more styrene-free product lines[60, 61, 62] and cobalt-free cure[63, 64]. Although styrene-free unsaturated resins had already been available for decades, the market never converted to these new resins except for very specific segments such as relining. This was partially because of the price, partially for technical reasons, partially because of the level of professionalism of the composites workshops, partially because workshops had no real trouble keeping below their emission limits especially during an economic crisis. The one country that was really strict on styrene seemed to be Denmark. With its history of windmill blade manufacturing, in the old days in large open moulds, they had their fair share of styrene emission,

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[60] AOC Ecotek 2011, http://www.aoc-resins.com/web/site/productinfo/C91/

[61] 2013, CCP Encore Prime
http://www.jeccomposites.com/news/composites-news/encore-prime-ccp-composites-styrene-free-product-range

[62] Reichhold Advalite hotmelt resins

[63] OMG: http://www.omgi.com/pdfs/Formulation%20Guide%20300-2.pdf

[64] Umicore: http://www.usmb.be/en/Applications/UPR/

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which led to a national preference for epoxy resins. However, in 2010 styrene received a new classification in the USA. It was listed as a 'reasonably anticipated carcinogen' in NTP's 12^{th} Report on Carcinogens[65], which created the momentum for the styrene-free resins to get their breakthrough. In Europe one of the market leaders, DSM Composites Resins, grasped the opportunity to introduce a new Atlac Premium range of styrene-free resins[66]. In addition to this, it also introduced a technology for cobalt-free cure, BluCure, together with AkzoNobel[67]. The implications for the industry of a shift in legislation could have been enormous considering it was already heavily hit by the economic crisis. Counterstatements were, however, formulated[68, 69], and it is a credit to the ACMA (American Composites Manufacturers Association) that it was able to mobilize its industry to form a lobby and bring more scientific evidence supporting the contrary to the table[70]. Whatever direction the styrene debate takes, it cannot be denied that it has to be viewed positively when workers' health and the environment can be protected simply through the use of better resins or by cutting emissions on the shop floor. So the advancement of these new technologies can only be viewed positively.

A second trend in cleaner technologies that has come on strong in the past five years is the advancement of thermoplastic composites, which became visible as a result of the market introduction of more reinforcements developed specifically for thermoplastics[71, 72, 73, 74]. Traditionally, glass fibre manufacturers estimated the global market to be divided into two-thirds thermoset and one-third thermoplast. A shift has been seen in recent years. Again, we are not talking here about a new trend, since thermoplastic composites have been around for a long time and most thermoplast volume is consumed as chopped strand in transportation and electronics. The increasing need for

[65] This report has in the meantime been replaced: http://ntp.niehs.nih.gov/pubhealth/roc/roc13/index.html

[66] 2011, DSM Styrene free à la Carte, http://www.jeccomposites.com/news/composites-news/styrene-free-la-carte

[67] DSM and AKZO 2012, blucure.com

[68] Statement European UP) resin sector group on styrene free technologies, 2011: http://www.reinforcedplastics.com/view/21136/european-up-resin-sector-group-issues-statement-on-styrene-free-technologies/

[69] http://www.compositesworld.com/articles/styrene-cobalt-headed-for-the-exit

[70] *Cancer Mortality of Workers Exposed to Styrene in the US Reinforced Plastics and Composite Industry in Epidemiology*

[71] http://www.reinforcedplastics.com/view/21122/3b-introduces-single-end-roving-for-polyamide-composites-at-composites-europe-2011/, http://www.compositestoday.com/2013/03/3b-fibreglass-introduce-new-roving/

[72] http://www.reinforcedplastics.com/view/37802/johns-manville-introduces-new-chopped-strand-glass-fibre/, http://news.jm.com/press-release/fibers/johns-manville-introduces-high-performance-fibers-pp

[73] http://composites.owenscorning.com/news.aspx

[74] http://www.agy.com/agy-introduces-new-sizing-system-for-a-wide-range-of-thermoplastic-resins/

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lightweight construction in the transportation sector, both automotive and aviation, has led to a new wave of creativity since various technologies are racing to gain as much market share as possible, especially in the automotive market[75, 76]. Compared to thermoset, thermoplastics are holding a very strong card because they can claim zero emission, zero chemistry, fast cycle times and automation. The drawbacks associated with these materials are their high investment costs for processing both in terms of presses and moulds, although the bigger the series (as in automotive) the more economically viable the process becomes. A technical drawback associated with these materials remains their stiffness. For larger composite parts, such as big spoilers for trucks and trailers, there will always be room in the market for SMC/BMC. It can be said though that the awareness of cheaper thermoplastic options based on PP or PE and glass seem to be opening doors that previously remained shut. A major milestone in the Dutch thermoplastic history has been the creation of the ThermoPlastic composites Research Centre, TPRC, by Boeing, Fokker, TenCate and the University of Twente[77].

Thermoset composites greatest strength, their durability, is, in a way, also what holds them back. Near indestructability makes recycling very costly but worth it (pyrolysis to recover carbon fibre composites) to almost not worth it (grinding of UPR into filler material) making the European Union approval of the cement kiln route for recycling of composites in 2011 very tempting. Using this route, compliant with the European Waste Framework Directive 2008/98/EC[78], which can be seen as a form of co-processing, the carbon footprint of cement can be reduced 16%[79]. In the past 10 years, however, several initiatives have popped up to try and recycle production waste and end-of-life composite parts[80, 81]. The challenges lie in the logistics (storing and transporting great big parts of composites), in the technical challenge (quality of recycled raw materials) and, partially, in the low commercial value of recycled GRP, which represents the bulk of the industry.

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[75] European Thermoplastic Automotive Composites consortium ETAC, 2012

[76] http://www.tencate.com/news/2013/TenCate-and-BASF-welcome-Owens-Corning-as-partner-in-alliance-for-thermoplastic-automotive-composites.aspx

[77] TPRC.nl

[78] "Glass fibre reinforced thermosets: recyclable and compliant with EU legislation", 2011, http://csmres.co.uk/cs.public.upd/article-downloads/EuCIA-position-paper-52816.pdf by the EuPC, EuCIA and ECR

[79] Composites Recycling Made Easy, EuCIA, http://www.avk-tv.de/files/20130212_recycling_made_easy.pdf

[80] Reinforced Plastics, September/October Issue 2014, "Recycling Composites Commercially" page 32-38 by Stella Job

[81] Reinforced Plastics, September/October issue 2013, Recycling Glass Fibre Reinforced Composites – history and progress", page 19-23 by Stella Job"

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In an attempt to improve the sustainability of composites, the next trend that emerged was bio-composites[82, 83]. Again nothing new, but the temptation to be able to disconnect the supply and raw material costs from oil finally took ground. In some cases, technical advantages can be found in reduced damping and noise absorption, but mainly the benefits are the carbon credits and reduced depletion of fossil-based resources. Whereas the bioresins currently on the market, which have been developed by the traditional UPR suppliers in the market, are mainly traditional resins with a portion of biobased building blocks and positioned as drop-in solutions[84, 85, 86, 87, 88], the biofibres on the market are actually in their primary form: fibres from flax, hemp, jute, kenaf[89, 90]. Whereas the weight and carbon footprint of these fibres compare very favourably to glass, a big problem with the natural fibres lies in the crop-to-crop differences. In order to tackle this problem, associations and projects were set up (in e.g. France[91], Belgium[92], UK[93]) to try and produce natural fibres and fabric materials of a consistent quality.

The one market that grew despite the economic crisis, was wind energy with an increase in installed capacity from 7.3 GWatt in 2002 to 45.2 GWatt in 2012[94]. This meant that the market for thermoset resins in wind energy grew from roughly 22 ktons to around 145 ktons. For the epoxy resin manufacturers the wind energy market became their biggest growth market in composites, as they supplied an estimated 14 ktons of resin in 2002 versus 110 ktons of resin in 2012.

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[82] Biocomposites reinforced with natural fibers: 2000–2010, Progress in Polymer Science 37 (2012) 1552–1596 by Faruka. Bledzki, Fink and Sain

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From monomer to macromolecular network: the plastic hotspot.

Another very positive trend over the past 10 years has been a wider acceptance of composites in markets that rely heavily on case history. Civil Engineering has opened up to composites[95, 96, 97] and the number of bridges built or repaired with composites has been growing slowly but steadily[98, 99, 100, 101]. The actual cost of a composite bridge is high, although the durability of the materials is what creates the tipping point[102]. Needless to say that when the market is tight these high costs become increasingly unacceptable and it becomes only too tempting to go back to cheaper, traditional materials with well-known case history instead of opting for a composite bridge which will save on future costs. On the positive side, the trend that architects and building designers receive incentives to use sustainable materials and methods has helped make people look at composites in a different light[103, 104]. What could be more environmentally friendly than a material with great durability? On top of that, the building incentives have triggered composites manufacturers to create more environmentally friendly products[105]. Again the ACMA has to be credited for playing a crucial role in material acceptance. They succeeded, for instance, in getting pultruded composites accepted into the building code, thus opening the doors for composite window frames[106].

In the Netherlands, a review of the CUR96 2003 has begun. The CUR 96 is a recommendation for fibre reinforced plastics in civil engineering supporting structures and, just like the British and German codes, it is not as comprehensive as the norms that are available for steel, wood and concrete. On top of that, it is not in line with the new Eurocodes.

The new CUR, CUR 96+ 2015, should bridge these gaps. It will be a recommendation for fibre rein-

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forced plastics in building construction[107] *and* in civil engineering supporting structures. The aim is to bring the code in line with the Eurocodes and to make it comprehensive in relation to the use of both glass and carbon fibres. It should, however, also open the door for other composites[108].

The long-term effects and calculation factors relating to water exposure, temperature, creep and dynamic modulus will be included in the new CUR96+. A project is currently running within the Professorship to establish the long-term calculation factors that can be used for the use of a flax reinforced composite in a movable pedestrian bridge intended for the Zoo in Emmen. The aim of this joint project with Stenden University of Applied Sciences is a five-meter-long bridge without counter-weight, hence the need for a lightweight bridge deck.

6.2 Focus on: Hybrid design and LCAs

Oil scarcity has been one of the triggers for composites to bloom, but according to Grantadesign[109] Cambridge more materials will become scarce, including, for example, steel. It is hard to believe steel will become scarce in the next 25 years, but with the high durability of buildings and massive production of machines, whether stationary or moving, a shortage of steel is predicted. Furthermore, if the world had the wish to totally convert to wind energy, there simply would not be enough steel.

Overijssel as a region has a strong manufacturing industry combined with agriculture and engineering firms. It is, therefore, not surprising that Windesheim's Engineering & ICT Educational Division has set up its education in such a way that it can fulfil the regional demand for employees. It does this by offering programmes in Civil Engineering, Building and Infrastructure, and Mechanical Engineering.The advantage of being a university of applied sciences and not a company is that there is complete freedom in material selection and design.
What is the best choice of material? What will last longest? What will show the best performance? The chosen focus of the team is, therefore, hybrid design. This means designing, for example, machines or civil engineering structures that are only part composite with the design supported from an eco point of view by life-cycle assessments. Using this filter future projects will be selected to help build up the very specific knowledge that is needed for hybrid design.

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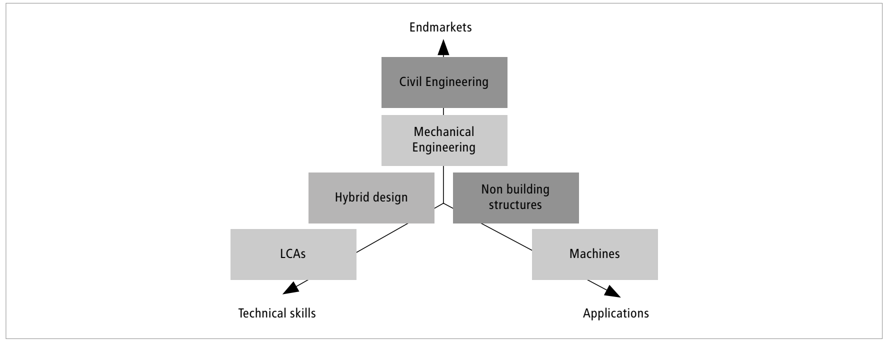
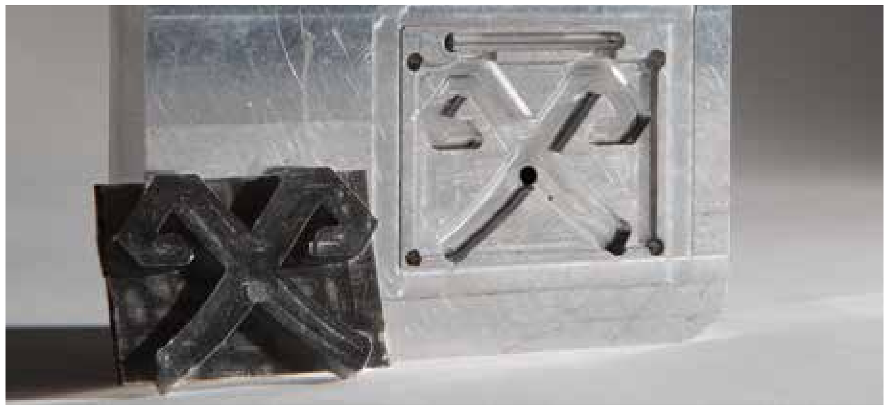


Focal point for composites: hybrid design.

6.3 Past and present activities in composites

The first project of the team on composites was on thermoplastic composites, a SIA Raak sponsored project entitled High Tech Plastics *(High Tech Kunststoffen)*. This project is still running.

This project investigates what thermoplastics composites, normally only applied in high-end applications, can bring to local industry. The challenge is to design and make a valuable end product for 12 SMEs. One of the outputs of the project was a study into overmoulding, which involved injection moulding onto composites and investigating the parameters that influence the adhesion of the injection moulded part onto the composite. Other subprojects involved thermoforming, tape laying and welding studies for, for example, side panels for wheelchairs, pulley blocks for the marine industry and the reinforcement of fermentation containers.



"High Tech Plastics": overmoulding

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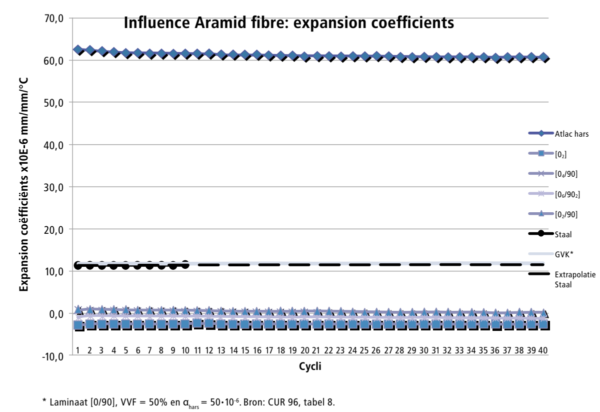
The second project on composites was on low thermal expansion bridge decks. Together with DSM Composite Resins and Teijin, composites were developed and designed that showed zero to low thermal response based on the expansion of specific aramid fibres whilst cooling in combination with the opposite behaviour by the resin. The advantage of such composites could be a a new bridge design that does not have to take thermal expansion into account.



Project "Composites in Built Environment": Influence of Aramid fibre on composite expansion coefficients.

This means that expansion joints can be eliminated, which, in turn, will lead to a reduction of noise whilst driving over the bridge. Although good results were achieved in terms of the thermal expansion of the composites (zero to low thermal expansion), it was shown by a Life Cycle Costing (LCC) analysis that financially no advantage could be found over normal bridge decks due to the high price of the specific aramid or carbon fibres needed to obtain these special properties.

However, the third project on rubber bearing pads did appear to be financially attractive. This was again a project within the Civil Engineering department, involving companies such as Vilton, Calenberge Ingenieure (D) and DSM Composite Resins. The non-corrosive properties of composites were used to develop rubber bearing pads that consisted of rubber and composite vulcanisates instead of the traditional rubber / steel pads. Hundreds of these pads are located under each of the precast girder viaducts and their lifespan is normally around 50 years. With the new composite bearing pads, the EN1337-3 norm of a horizontal displacement of twice the height of the rubber could be achieved. In addition, their estimated life span of 100 years (equal to bridge deck) means that fewer traffic disruptions can be expected as a result of maintenance and the replacement of these pads under the viaducts.

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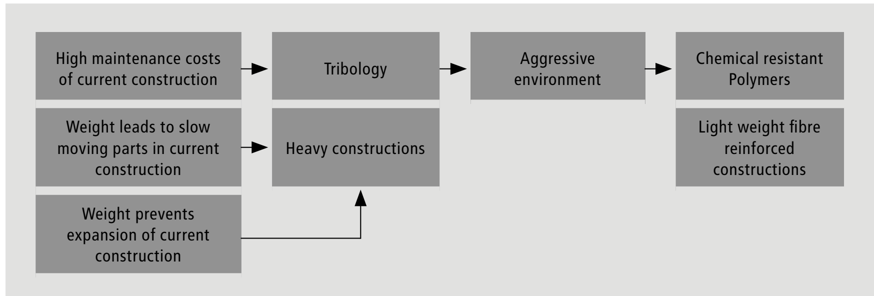
Project “Composites in Built Environment”: Shear test of rubber bearing pads.

The most recent composite project of the team started in September 2014 and explores the possibilities of (fibre reinforced) plastics in Applied Mechanics and machine building, according to the schedule below.

Seven different cases ranging from manure injector units to egg sorting machines, can washers and pelletizer machines are being investigated for redesign with composites and/or plastics.



Project “Composites and plastics in Applied Mechanics”.

7. Concluding Remarks

Considering all the industrial changes in the four chosen research programmes, we can conclude that there is certainly enough work for the coming decades. As industry responds to the needs of the consumer, to upcoming legislation and to oil scarcity, the trend will undoubtedly be towards smaller and thinner packaging, higher percentages of recycled material and lighter construction for transportation. Our research will mainly focus on balancing these aspects to the advantage of the students, the consumer, the industry and, ultimately, the environment. Like a seesaw, each strongpoint has its pitfall: composite durability versus indestructability, recycling versus degrading properties, processing improvements versus even fewer jobs in production plants. All aspects need to be weighed up against each other and balanced to arrive at the most rewarding overall solution.

Each of the research programmes has therefore a clear task ahead. For Recycling it means a deeper understanding has to be created of the material effects to help push recycling. For the programme on Sustainability in Plastics Processing it means the design and engineering of new equipment but also simulations to help create shortcuts in processing. For 3D Printing a wider industrial applicability of the technique needs to be created and for Composites a lot of groundwork has to be done to understand the way different materials work together.
Besides the technical aspects of these programme lines, each time the effect on the environment has to be taken into account.

The way forward in plastics will undoubtedly be energy-wise, raw material-saving and engineering-smart and as the Professorship envelops all the Engineering study Programmes, it is felt that the team can support the training of the socially engaged future Engineers, both at Bachelor and Master level.

Acknowledgements

I would like to thank the following persons for their help, knowledge, effort and, most of all, the fun we have.

Ineke van der Wal for your guidance, wisdom, warm heart and all the freedom you allow me in executing my job.
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The team: Wendy and Gertine (ladies first of course), Niels, Jakob and Otto, Robbie and Freek and Laurens and Jasper, Peter, Marc and Rik, Hans, Roy, Ruud, Ghassan, Koen, Cristian, Pieter, Tommie and Tijmen. I thank you not just for your enthusiasm and research with or without students, but also for your involvement in actively acquiring new projects, in networking and in knowledge dissemination. Thank you for helping me to establish the reputation of the Professorship.

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And a final thanks to Peter Bas Schelling (student), Geert Heideman and Niels Boks for suggesting the title for this book.

Persons not featured: Jasper Bouwmeester, Roy van Enkhuijzen, Koen Hermans.

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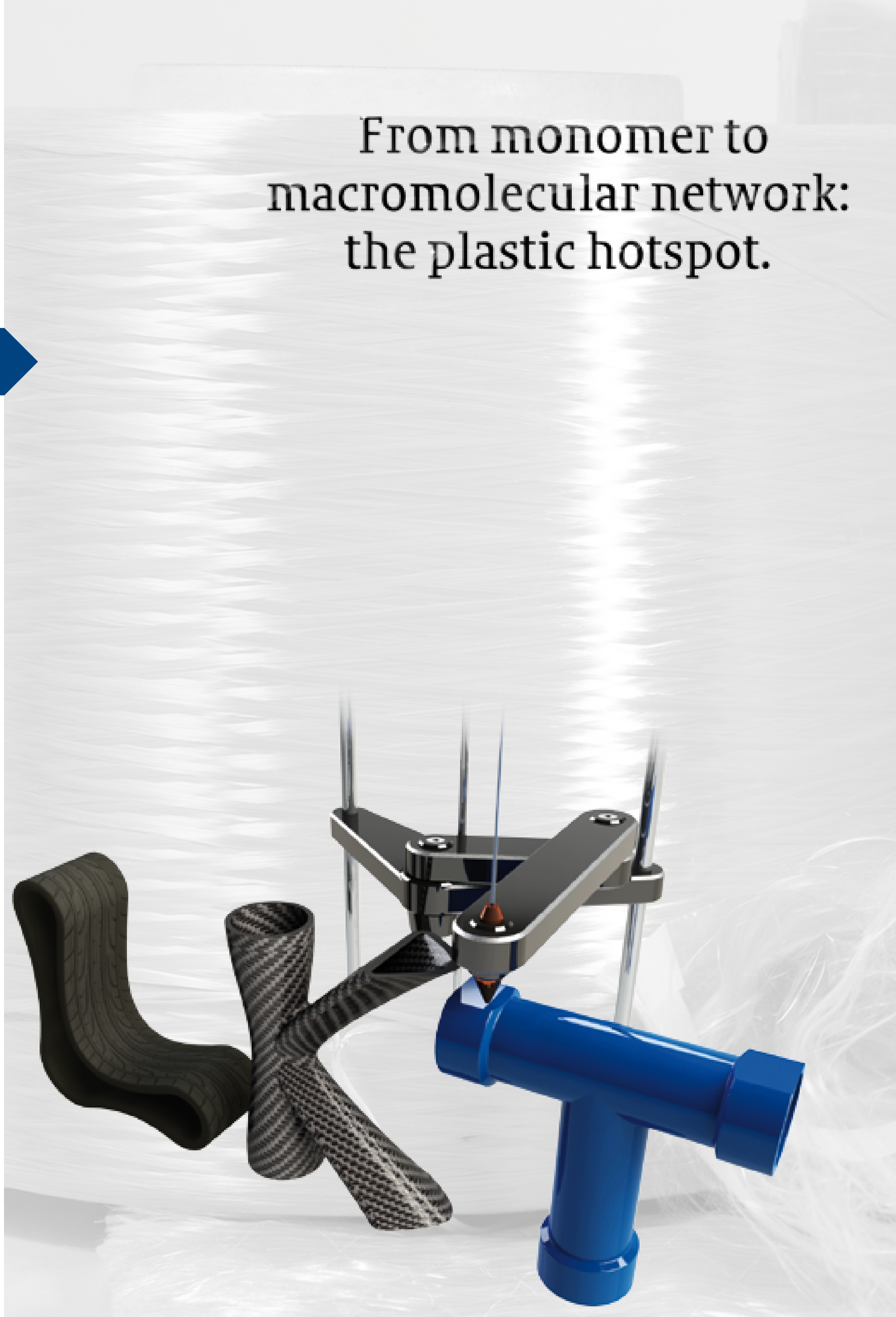

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Professorship for Polymer Engineering

MARGIE TOPP

Margie Topp studied Chemistry at the Faculty of Mathematics and Natural Sciences at the University of Groningen, specializing in Polymer Chemistry. She graduated in the year 1995 on impact resistance of poly(lactic acid) within the group of Professor A. Pennings. In 2000 she finished her PhD on emulsion polymerisation of temperature sensitive block copolymers as micellar delivery systems of anti-tumour agents. This work was carried out within the group of Polymer Chemistry and Biomaterials of Professor J. Feijen at the University of Twente.

From 2000 till 2012 she worked at DSM Composite Resins, where she developed her passion for composites and applied industrial research. She held various technical positions and she also spent eight years as a Business and Technical Intelligence Manager piecing together the world of composites from a market perspective in numbers, facts and predictions.

In 2013 Margie joined Windesheim University of Applied Sciences as a professor, running the research group on applied Polymer Engineering, 'het lectoraat Kunststoftechnologie'. This book is about what makes her job so exciting: the combination of knowledge build-up through applied research, the lecturers and students as researchers and the sheer variety of projects with the regional industry leading to real practical innovations.

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