Part I

The First Plastics Revolution

(1945-1970)

3. Manufacturing industry: production, processing and application

Plastics were the fastest growing industrial sector in the Netherlands after the Second World War, posting some amazing growth rates in the 1960s in particular (see Graph 3.1). Even *Plastica*, the trade journal for the Dutch plastics industry (which was pretty used to turbulent markets) was 'astounded to see that the hike in output from 79,500 tonnes in 1960 to 134,500 tonnes in 1963 is likely to be followed by a doubling in output over the next three years…'[1]

At the same time, in terms of output per capita, the Dutch still lagged a long way behind the pack leaders, West Germany and the US, a situation that was set to change quickly in the years ahead (see Table 3.1). Such was the speed with which plastics manufacturers raised their production capacity that, by the mid-1970s, production capacity in the Netherlands was the highest in the world in relative terms (see Tables 3.2 and 3.3).

Exports

The Netherlands was soon a big plastics exporter. According to an article in *Plastica*, in terms of kilos per capita, the country had become the world's leading exporter by the mid-1960s.[2] On the other hand, the Dutch were also big importers of plastics (see Tables 3.2 and 3.3). The fact was that the Netherlands played a vital role as a transit country – a role that was to change dramatically in later years. By the mid-1970s, together with West Germany, Japan and the US, the Netherlands was up there among the four biggest plastics exporters in the world in absolute terms (see Table 3.3).

The bulk of Dutch plastics exports went to West Germany and other European countries (see Table 3.4). Labour productivity in the Netherlands was high, and productivity per plant was also high, compared with the US, West Germany, Japan and some other countries. This was due mainly to the structure of the Dutch plastics industry, which revolved around high-volume production (see Table 3.5).

Consumption

Apart from exporting plastics, the Dutch were also consumers of plastics. Domestic consumption rose from 1.7 kg per capita in 1950 initially to 9.1 kg in 1960 and further to 35 kg in 1971. Initially, the Dutch consumed much less plastic than the Americans, who were the world's leading consumers. However, the gap between the US and the Netherlands (and other West European countries) narrowed in the 1950s, so that by around 1970, the Germans were the biggest plastics consumers, at 62 kg per capita per annum. This was over one and a half times as high as consumption in the Netherlands, and more than twice the amount consumed in the UK and Italy (see Table 3.6).[3]

So-called 'instant home' made of plastics, built by the Dutch company Fokker, 1964

Sale of nylon stockings by lottery in the Netherlands (1946). During World War II, nylon – which was needed for parachutes – had come into short supply for applications such as stockings, which therefore came under rationing.

Household goods (including furniture, furnishings and toys), textiles, electrics and electronics were the main markets for plastics both before and after the Second World War.[4] In addition to these traditional markets, three other sectors were also big users of plastics, viz. the building & construction, packaging and transport industries (see Table 3.7).[5] Building & construction and packaging were to evolve into the principal markets in the Netherlands and several other countries in the 1960s.[6] Despite the fact that plastics accounted for just 2% of all construction materials, such was the size of the construction industry that a 2% share of the market was equivalent to 29% of aggregate plastics consumption in the Netherlands.[7]

Building & construction

Plastics were put to all sorts of different uses. Apart from in toilets and bathrooms, washbasins, kitchen worktops, gutters, rain pipes, drainpipes and other water pipes, they were also used as building materials, albeit in non-load-bearing structures such as window frames, ceilings and partitions. Plastic film was used for damp proofing, for covering construction materials and for protecting construction sites from frost. Other applications included heat and sound insulation, the coating of steel plates and the construction of inflatable structures.

Packaging

Plastics were also used as packaging, during transport and for storing products in houses, shops and warehouses. They were used to make bags, boxes, bottles, containers and crates, and for shrink-wrapping magazines and foodstuffs. Even entire pallets loaded with products were wrapped in plastic.

Transport

The third market was transport, where plastics were used primarily in the automotive industry and shipbuilding. New cars built in 1955 contained an average of 5 kg of plastic, a figure that had risen to 45 kg by the year 1970. Hundreds of car parts were made of plastic, including cooling fans, fuel pipes, gearwheels for windscreen wipers, handles for sliding roofs, and front panels for car radios. The future potential was seemingly huge: cars consisted of some 13,000 components so there were plenty of opportunities for making further use of plastics.

Countless possibilities

In shipbuilding, a rosy future beckoned for polyester fibreglass boats, where applications were not confined to small boats and yachts alone. Fibreglass proved a viable construction material for relatively large boats – and not just pleasure craft. There was also interest in naval applications, for example, as radar found it hard to pick out boats made of plastic.

In short, the sky was the limit and between 24% and 35% of all applications were in areas other than those listed above. Plastics were used in the machine-building industry (as machine parts), in the paint industry (in producing paints and lacquers), in agriculture (in the production of wheelbarrows, feeding troughs and protective coverings), in shoe-making (as a leather substitute) and in the medical industry (for sterile packaging, injection syringes, plastic catheters, artificial bones, plastic tubing and so forth).

Plastics producing industry

These were all markets served by the plastics industry, which consisted of two main

Paint shop at the DAF factory in Eindhoven (Netherlands), 1959 components, i.e. the plastics producing industry and the plastics processing industry. To begin with the plastics producing industry, this was responsible for the three main bulk products produced after the Second World War, i.e. PVC (polyvinyl chloride), polyethylene and polystyrene. As far as the Dutch market was concerned, PVC was produced by Shell in Pernis and by DSM in Geleen at the beginning of the 1970s (see Table 3.8). Shell was the bigger of the two companies. DSM was the main producer of polyethylene, which was also manufactured by two foreign companies, Dow Chemical in Terneuzen and ICI in Rozenburg. Polystyrene was made by Hoechst in Breda and also by Dow Chemical. DSM and the Rotterdamse Polyolefinen Maatschappij (RPM) in Pernis (which was 60% owned by Shell) produced polypropylene.[8] Nylon was the most important synthetic fibre and was produced by AKU in Emmen and also by ICI. There were also various other plastics, which were manufactured both by DSM and by foreign concerns such as DuPont and General Electric.

Plastics processing industry

Shortly after the Second World War, the plastics processing industry consisted of 46 companies employing a workforce of almost 2,700 (situation in 1951). By 1960, however, the industry had expanded to comprise 230 businesses employing a total of 7,000 people. However, exactly which companies were and were not defined as forming part of the plastics processing industry was not entirely clear. On the basis of a limited definition, Statistics Netherlands claimed in 1968 that the industry consisted of 166 businesses (employing at least 10 people) and a total workforce of around 12,200. These businesses owned some 160 compression moulding machines, 370 extruders and 380 injection moulding machines.[9]

The plastics processing industry was initially dependent on American machines.[10] However, it was not long before European engineering firms also started to produce highly sophisticated machinery. West Germany was in the lead,

Polyester boat at the Macro Plastic Trade Fair in Utrecht (Netherlands), 1962

New oil refineries under construction at Pernis (Netherlands), 1967

followed by Britain, France and Italy. Dutch engineering firms played only a modest role, with Stork being one of the few companies producing machinery for the plastics industry.

Success factors

Growing prosperity and lower oil prices were two of the reasons for the revolution that took place in plastics after the Second World War. The potential plastics markets saw a period of unparalleled growth after the war. With oil prices at an all-time low, plastics were in a favourable starting position compared with other materials such as wood, metal, cotton and wool (see Graph 3.2 and Figure 3.1). Other factors paving the way for the revolution were the synthetic nature of plastics, their tremendous diversity, the ongoing improvements in functionality and the opportunities for mass production.[11] The latter were the results of the advances made in plastics technology.

That the Netherlands managed to build up a strong position for itself in the international plastics industry came as something of a surprise. After all, the Dutch had definitely not been among the leading exponents of plastics technology before the war. On the contrary, they lagged well behind the Americans, the Germans and the British. And the war actually widened the gap between the Dutch and the Americans. Within a period of about 25 years, however, the situation had totally changed: the Netherlands was up there among the world's leading plastics producers.

One of the main reasons for this turnaround was the availability of raw materials for the production of plastics. DSM was conveniently located above the coalfields in the south of the country. Shell had access to both oil and oil refineries on its Pernis site. Pernis and Europoort were to grow into the biggest oil storage and transshipment sites in Western Europe. The combination of these factors attracted foreign companies to the Netherlands. The plastics industry thus became a representative of a typically Dutch branch of industry: industrial processing based on trade flows.

There was yet another crucial factor: the Netherlands managed to master plastics technology and to acquire excellent skills in the production and processing of plastics. It was a difficult process that forms the subject of the next chapter.

TABLE 3.1 Plastics production per capita in various countries, in 1963 and 1975 (kg)

	Production per capita (kg) 1963	Estimated production per capita (kg) 1975
West Germany	24.3	78
US	20.6	45
UK	13.7	?
Italy	12.4	?
Netherlands	11.2	106
France	10.5	41

SOURCE: For 1963, see A.G. Wansink, 'De Nederlandse kunststoffenindustrie in 1963 en enige toekomstaspecten', *Plastica* 17 (1964), no. 9, 453, table IV. For 1975, see 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31 (1978), no.1, 2, table 4. Table 4 contains data on per capita consumption in the various countries. These figures have been converted into production per capita using the aggregate production and consumption figures in table 2. See note 24 in Part I on the reliability of the data.

TABLE 3.2 Estimated production, imports, exports and domestic consumption of plastics in various countries, in kilotonnes (1963)

	Production (kton)	Imports (kton)	Exports (kton)	Domestic consumption (kton)	Net exports (kton)	Aggregate availability = production + imports = domestic cons.+ exports
US	3,900	80	478	3,502	398	3,980
West Germany	1,400	156	420	1,136	264	1,556
UK	737	151	266	622	115	888
Italy	625	54	244	435	190	679
France	508	143	156	495	13	651
Netherlands	134	105	124	115	19	239

SOURCE: A.G. Wansink, 'De Nederlandse kunststoffenindustrie in 1963 en enige toekomstaspecten', *Plastica* 17 (1964), no. 9, 453, table II, in combination with H.B. Sprietsma, 'De betekenis van de Nederlandse kunststoffenexport', *Plastica* 19 (1966), no.12, 571, graph 2. The import and export percentages in this graph refer to 1964 and have been used for 1963.

TABLE 3.3 Production, imports, exports and domestic consumption of the plastics producing industry in various countries in 1975

	Production (kton)	Imports (kton)	Exports (kton)	Domestic consumption (kton)	Net exports (kton)	Aggregate availability = production + imports = domestic cons.+ exports
US	9,626	76	1,002	8.620	926	approx. 9,662**
Japan	5,167	79	1,260	3,986	1,181	5,246
West Germany	6,446*	1,517*	2,431*	5,532*	914*	7,933*
France	2,030	911	901	2,040	-10	2,941
UK	1,968	335	363	1,940	28	2,303
Netherlands	1,376	409	1,450	335	1,041	1,785
Sweden	440	370	255	555	-115	810
Australia	366	133	34	455	-99	approx. 495**

SOURCE: 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31 (1978), no.1, 1, tables 2 and 3. See note 3 on the reliability of these figures.
* These figures refer to 1976.
** In these countries, the sum total of production + imports does not equal the sum total of domestic consumption + exports. The discrepancy is not very large. The figure quoted is the average of the two totals.

TABLE 3.4 Dutch plastics exports in kilotonnes per importing country, 1970

	Country	%
West Germany	309	33.8
Belgium and Luxembourg	122	13.3
France	116	12.7
Italy	57	6.2
EEC (subtotal)	**604**	**66**
UK	43	4.7
US	7	0.8
Scandinavia	80	8.7
Others	181	19.8
All countries, excl. EEC (subtotal)	**311**	**34**
Total	**915**	**100**

SOURCE: H.B. Sprietsma, 'De Nederlandse kunststoffen-industrie in 1970', *Plastica* 24 (1971) 5, 203, table 10.

TABLE 3.5 Output, production plants, workforce and productivity of the plastics producing industry in various countries in 1975

	Output (kton)	Workforce	Number of production plants	Labour productivity (in tonnes per employee)	Plant productivity (in tonnes per plant)
US	9,626	360,000	8,000	26.7	1,203
West Germany	5,047	179,378	1,976	28.1	2,554
Japan	5,167	112,642	13,354	45.9	387
France	2,030	84,000	1,300	24.2	1,562
UK	1,968	117,800	2,500	16.7	787
Netherlands	1,376	15,700	240	87.6	5,733
Sweden	440	37,000	800	11.9	550
Australia	366	30,833	759	11.9	482

SOURCE: 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31(1978), no.1, 1, tables 2 en 3.
Note: Plastics production in the Netherlands centred on bulk plastics. This is probably the main reason for the differences in labour and plant productivity between the Netherlands and other countries.

TABLE 3.6 Estimated plastic consumption per capita in various countries, in 1950, 1960 and 1971 (in kg per annum)

	1950	1960	1971
US	6.4	13.8	42
UK	2.3	8.7	27
West Germany	2.2	13.6	62
Netherlands	1.7	9.1	35
Italy	0.9	5.4	29
France	0.9	7.2	34
Japan	0.2	5.9	37
Sweden		11.0	35
World			9

SOURCE: A. E. Schouten and A.K. van der Vegt, *Plastics. Hoofdlijnen van de huidige kennis en toepassing van de synthetische macromoleculaire materialen* (Utrecht 1966, 5th edition 1974), 278, table 11.4.

TABLE 3.7 Plastics consumption in various countries in 1975, by market (%)

	Building & construction	Packaging	Transport	Household articles	Electrics, electronics and domestic appliances	Furniture and furnishings	Miscellaneous
Netherlands	29	23	6	5	3	1	33
Australia	22	19	5	4	10	9	31
UK	20	25	6	5	8	5	31
US	17	27	7	10	9	6	24
Japan	14	28	5	8	10		35

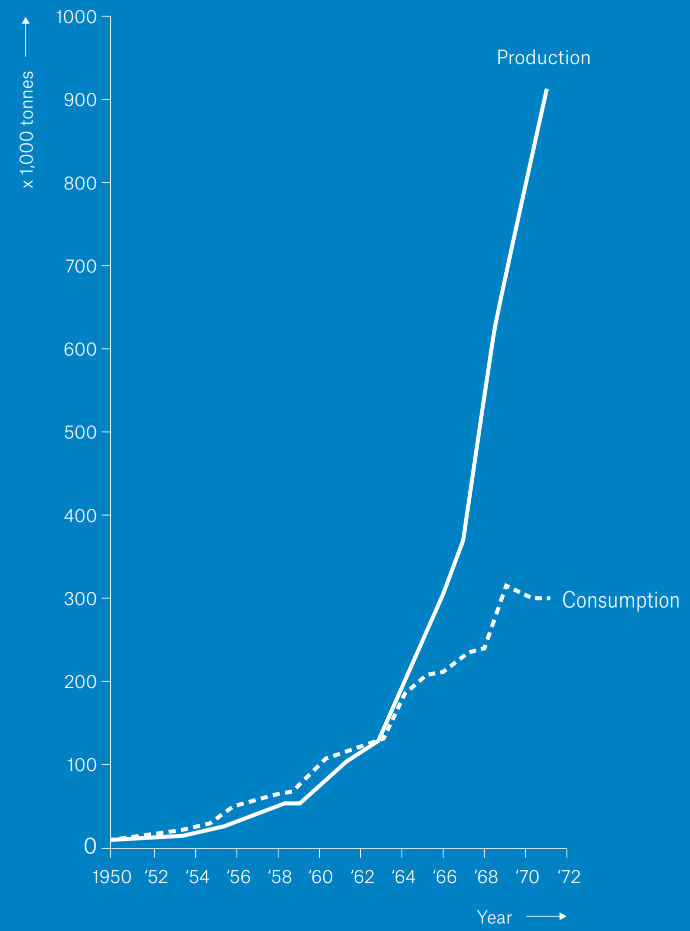
SOURCE: 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31 (1978), No.1, 1, table 6.

TABLE 3.8 Leading plastics producers in the Netherlands in 1973

Name of company	Type of plastic produced
DSM	PVC, polyethylene, polypropylene, ABS, SAN, melamine resins
Shell	PVC, epoxy resins
RPM*	Polypropylene
AKU	Nylon, PETP (fibre)
Foreign companies:	
- Dow Chemical	Polyethylene, polystyrene, ABS, SAN
- ICI	Polyethylene, nylon, PMMA, PETP (film)
- Hoechst	Polystyrene
- RPM*	Polypropylene
- Marbon	ABS
- General Electric	Noryl, PC
- DuPont	POM, PTFE

SOURCE: A. E. Schouten and A.K. van der Vegt, *Plastics. Hoofdlijnen van de huidige kennis en toepassing van de synthetische macromoleculaire materialen* (Utrecht 1966, 5th edition 1974), 280-281, table 11.3. See also: H.B. Sprietsma, 'De Nederlandse kunststoffen-industrie in 1970', *Plastica* 24 (1971) 5, 198, table 1.
*RPM was 60%-owned by Shell.

GRAPH 3.1 Production and consumption of plastics in the Netherlands, 1950-1972

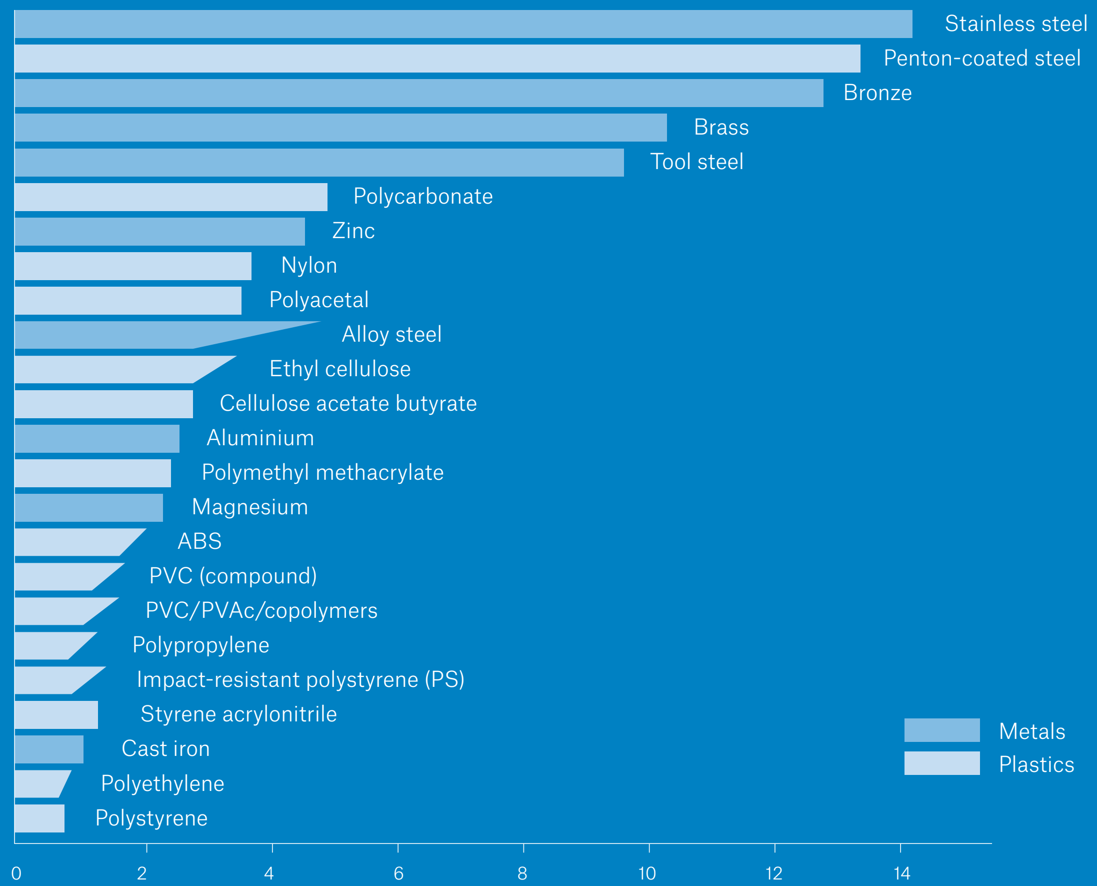


SOURCE: H.B. Sprietsma, '5 miljoen ton kunststoffen in 25 jaar', *Plastica* 25 (1972) 12, 543, graph 1.

GRAPH 3.2 Falling prices of various plastics and natural rubber, 1956-1964 (in Dutch guilders per kg)

SOURCE: : J.M. Goppel, 'Nieuwe kunststoffen, verwerkingstechnieken en toepassingen in Nederland', *Plastica* 18 (1965) 9, 430, figure 5.

FIGURE 3.1 Cost comparison of metals and plastics on volume basis, US, 1965 (in dollar cents per cubic inch)



SOURCE: J.M. Goppel, 'Nieuwe kunststoffen, verwerkingstechnieken en toepassingen in Nederland', *Plastica* 18 (1965) 9, 432, figure 8.

Plastic pipes

It took a long time for certain plastic products to be accepted for everyday use. It was many years, for example, before PVC pipes were accepted by plumbers and gas fitters working in the building & construction industry. PVC piping first appeared on the market in around 1950. At first, there was not much difference in price between plastic and copper piping, so that copper remained the material of choice. Professionals were used to working with copper, and were wary of the unknown risks that might be involved in making the switch to plastic. In 1949, a manufacturer of plastic pipes called Polva applied to KIWA, a testing and certification body for water piping products, for a 'KIWA Quality Mark'. Once KIWA had drawn up a list of certification criteria in conjunction with the TNO Plastics Institute, Polva found that it needed to increase the wall thickness of its plastic pipes. In the meantime, a competitor called Wavin had also applied for the same quality mark, which it was awarded in April 1954.

The outbreak of the Korean War in the early 1950s led to a sharp increase in the price of copper, lead and steel, which in turn encouraged water companies, engineers, contractors and architects to take more interest in plastic pipes.

Nevertheless, despite this growing interest, plastic piping did not feature in the 1956 edition of the official manual for the water industry, published by the Association of Dutch Water Company Operators (VEWIN). A textbook for secondary technical schools published the following year did however discuss the use and processing of plastic pipes.

Warehouse of Polva, a Dutch pipe manufacturer

Preparations underway for laying plastic water supply pipes

As a potential market for miles and miles of plastic piping, the water companies formed the plastic manufacturers' prime targets. The latter did not supply fittings such as bends and tees (T-fittings), however, as the fitters working for the water companies preferred to make all the connecting pieces and brackets themselves. For plumbers working in the building & construction industry, fittings such as bends and tees were a vitally important means of joining plastic pipes. The job of making branches, bypasses and Y-pipes proved a tough one and the widespread use of plastic piping was hindered by the lack of fittings. In 1954, Wavin performed a series of tests with connecting pieces and organised a contest among its staff to find alternative options. It eventually started producing plastic fittings in 1958.

Once fittings and other technical devices such as valves could be introduced into a system of pipes with the aid of the conventional method of flanges, and once the pipes themselves became subject to certification, the popularity of plastic piping soon began to grow. By 1961, the use of plastics for a wide range of pipes and tubes had become so commonplace that the prices were listed in a trade journal. It is clear from the recommended prices that electrical piping, water supply pipes, drain pipes, sewage pipes and rainwater pipes were cheaper when made from plastic than when they were made from the materials originally used for such purposes. In short, plastic pipes had acquired a permanent place for themselves.

SOURCE: E.M.L. Bervoets and F.C.A. Veraart with assistance from M.Th. Wilmink, 'Bezinning, ordening en afstemming 1940-1970', in: J. Schot, H. Lintsen and A. Rip, *Techniek in Nederland in de twintigste eeuw* (Zutphen 2003), Part VI, 224-229.

4. Plastics: platform, research and development

Plastics technology as an industry platform

As principally the products of scientific research, plastics acquired a contemporary, scientific image in the 1930s. The main novelties of the pre-war years, materials such as PVC, nylon and polyethylene, originated in the research laboratories of big chemical companies.[12] Slowly but surely, researchers began to understand more and more about the chemical structure of plastics.

The process was given a big helping hand by the concept of a 'macromolecule', a term that was coined by Hermann Staudinger, a German professor, in 1924. It referred to molecules consisting of a very large number of interconnected atoms (see Box 2). Staudinger reduced the complex structure of a plastic to a chain of repeated atomic patterns (or monomer units). In other words, a 'macromolecule' or 'polymer' is made up of a chain of one or more monomers.[13] The macromolecule concept gave researchers a better understanding of the processes underlying the formation of plastics.

A turbulent period of global research into – and theorising about – plastics and polymers followed. The chemical industry invested massive amounts of money in research, including research into plastics. In 1959, out of all Dutch industries, it was the chemical industry that spent most on research, as measured in terms of either the percentage of turnover spent on research (1.5%) or the amount of money spent per employee (797 guilders). The chemical industry also employed the largest number of university and technical college graduates (at 17.6 and 24.6 per 1,000 employees respectively).[14] With good reason, the chemical industry was regarded as being science-based.

Melamine was a relatively expensive but durable product, marketed by DSM for laminating kitchen elements and as a raw material for tableware.

The craft of plastics processing

And yet this is just one side of the coin. The plastics producing industry may have been science-based, the plastics processing industry was most definitely not. Indeed, the processing of plastics was seen as more of a craft than an industry. Han Meijer, researcher at DSM in 1986, described the situation as follows: 'In the old days, people would start out by setting up a second-hand machine in a shed and, using a bag of plastic granules, either injection mould or extrude plastic products.'[15] This was also the image that was used to justify the institution of Meijer's part-time chair at Eindhoven University of Technology, where he researched the modelling of plastics processing.

Nonetheless, the authenticity of his description is borne out by those who witnessed the beginning of plastics processing. A manufacturer of plastic products complained about the amateurism

Hermann Staudinger

in the industry: ‘When moulding machines are demonstrated at exhibitions and trade fairs, they are used to produce fairly simple products using easily processable materials and in many cases by automated processes. As a result, people tend to think that plastics processing is a piece of cake. “Hang on, that’s something I can easily do myself!” is what they think. Even private individuals start musing about the idea of building their own factory....’[16]

Not so easy

The image presented above is an exaggeration, of course. Even in order to manufacture the simplest of products, plastics processors had to think carefully about the production process and gain experience. They had to make a choice from a huge variety of plastics, machines and moulds. If they wanted to have a new mould made for a product design of their own, they would first need to make the necessary technical drawings, work out the best possible mould construction and then find an experienced mould-maker to do the job for them. Mould-makers needed to factor in material shrinkage, for example, given that plastics tended to lose up to 10% of their volume as they set in the mould and during the rest of the cooling process.[17]

Production itself also required experience: for example, the machine temperature and the cycle time needed to be set very carefully, as the quality of the product depended on them. And things could always go wrong. For example, products made of urea resins had to be very carefully cured. The exterior of the product might well be fully cured even though the interior was still in the process of curing. This meant that the interior was easily capable of absorbing moisture and swelling up as a result, leading ultimately to the product exploding.[18]

Plastics processing was about more than just injection moulding, compression moulding and extruding. Depending on the nature of the product, processors would have to be capable of welding, gluing, clamping, hot-forming, cold-forming, lathing and polishing. In short, plastics processing required a number of essential skills and experience.

New companies

Yet it was fairly straightforward to start a plastics processing plant, especially if simple products were involved. So it was that, in 1950, two friends started producing plastic hammerheads, ink pots, stamp dampers and screwdriver handles in a tiny shed in the southern Dutch town of Eindhoven. Just a few years later, they were already exporting their products to other countries and even opened a branch in Venlo to cater for the German market. Thus was born a firm called Tiger Plastics, which is known today mainly as a producer of bathroom articles and which has outlets in almost every European country and in Japan.

Old companies

Operating alongside the young start-ups were the established companies, who might set aside a corner of one of their production halls to explore the possibilities of working with plastic. They realised there were good opportunities to manufacture either entire products or certain components from plastic. These companies had the advantage of knowing both the market and the requirements that their products needed to meet.

One of them was called *Hollandsche Draad- en Kabelfabriek* (‘Dutch Wire and Cable Factory’, or Draka for short). The company was extremely interested in the possibility of using plastic as cable sheathing and in 1947 it set up a special division known as Draka Plastics for this purpose. A few years later, it started producing plastic piping.[19]

In 1953, Verblifa (whose full name was *Verenigde Blikfabrieken*, or ‘United Tin Factories’), a manufacturer of tin packaging materials, started producing polyethylene tubes and bottles.[20] And in 1956, a company called Beccon Doetinchem (a metal casting, enamelling, galvanising and tinning plant) began making a range of household articles from polyethylene.[21]

Traditional plastics producers

The third and final category consisted of companies that had traditionally been members

Laying plastic water supply pipes underground at Odijk, near Utrecht (Netherlands), 1953

The director of Dutch manufacturer WAVIN demonstrates the shape retention properties of his company's plastic pipes by having a car driven over a water pipe.

of the plastics processing industry and that had already manufactured plastic products before the war. These included *Nederlandsche Omnite Fabriek* ('Dutch Omnite Factory'), which had been founded in 1928,[22] and *Gebr. Van Niftrik* ('Van Niftrik Brothers'), which dated back to 1929. All these businesses already had considerable experience with the processing of plastics.

Platform-like industry

All in all, companies were quick to learn how to process plastics. The fact was that it was relatively easy to join the plastics processing industry – easier, at any rate, than it was to join the plastics producing industry. This was all to do with the platform-like nature of the plastics industry. The industry rapidly evolved after the war into an open network of production companies, laboratories and knowledge institutions. The members of the industry worked with a common set of technologies and standards that formed the basis for joint innovations. Newcomers were able to form alliances with different parties and thus launch new activities.

At the heart of the platform were the big plastics producers, companies such as DSM, Shell, Dow Chemical and ICI, big engineering firms like Stork, and organisations such as AKU and the Netherlands Organisation for Applied Scientific Research (TNO), in the form of the TNO Plastics Institute (which later became the TNO Plastics and Rubber Institute, KRITNO). It was they who produced the plastics and semi-finished products, who had research labs that enabled them to roll out foreign innovations in the Netherlands, develop new plastics and processing machines, and supply plastics with specific properties to suit a client's specific requirements. TNO also played a key role in the development of standards for the supply and use of plastics. Within this constellation, the universities were conspicuous by their absence.

Plastic piping for water mains

A good example to illustrate the role played by the plastics platform is the production of plastic piping by the regional water supply company for the Dutch province of Overijssel.[23] Before the war, water mains were made of cast iron and lead, and tended to corrode as a result of the combined action of water and soil. Although there were two standard alternatives, i.e. copper and asbestos cement, there was also the possibility of producing plastic piping.

When the water company needed to expand the water distribution system in one of its districts in the early 1950s, it decided to take a serious look at the possibility of manufacturing its own mains. The problem was that Dutch manufacturers were simply unable to supply asbestos cement pipes in the quantities required by the company, while foreign-produced pipes were prohibitively expensive. The company decided that the answer lay in starting its own plastics processing operation and to produce PVC water pipes. It decided to call in the help of Shell, which was known to have been producing PVC since 1950. Together, the two firms approached manufacturers of extrusion (injection) moulding machines in Paris and Luxembourg. Although the demonstrations and experiments were not unqualified successes, the water company nonetheless decided to buy an extruder.

A further series of experiments followed in the Netherlands, aided by Shell, on the basis of which the machine was deemed to be capable of producing small-diameter piping. The production costs represented one third of the market price of copper piping and half that of asbestos cement piping. The resultant savings were invested in a further series of experiments. With large-diameter pipes proving difficult to manufacture, it was decided that what was needed was a dedicated programme of research, plus talks with the Luxembourg-based manufacturer of the extrusion press.

All in all, the production capacity of the equipment far exceeded the water supply company's needs. When talks with another manufacturer of plastic piping failed to deliver a successful outcome, the company decided it might just as well sell the pipes itself and to this end set up a sales company of its own. Electricity pipes formed an attractive potential market and a distribution contract was signed with a trading company called *R.S. Stokvis en Zonen*.

However, objections arose to the company's decision to launch a sales company of its own, on the grounds that this represented an undesirable mixture of public and commercial interests. And so, in 1955, the company incorporated a new company with three shareholders: itself, Shell and Stokvis. It was called Wavin, an acronym made up of the Dutch word for 'water pipe' and 'vinyl'. In short, one of the regional water supply companies in the Netherlands had produced a successful innovation with the aid of the plastics platform. It is worth noting that the platform also included a number of foreign parties.

Nylon stockings

There were also instances in which the plastics platform had very little to contribute. For example, when a hosiery manufacturer called Jansen de Wit first decided to produce nylon stockings, this proved to be a fairly easy process involving only a small number of parties.[24] It was not long before news of the success of nylon stockings had reached all corners of the Netherlands. As soon as the Second World War ended, Dutch hosiery manufacturers decided that they wanted some of the action. Despite the shortage of nylon in the Netherlands, Jansen de Wit had nonetheless managed to obtain a small quantity through its foreign contacts and began experimenting with it. The company had read in the literature (and had also been told by other manufacturers) that it would need to adjust its knitting machines to the new material. After visiting machine traders and manufacturers in the US, one of the directors, Mathieu Jansen, selected a firm called Lieberknecht as the supplier of new machines for the company.

In the meantime, however, the Dutch firm AKU, which produced synthetic fibres, had succeeded in producing nylon. In 1950, AKU supplied the first batch of cones of nylon yarn from its pilot plant to Jansen de Wit, which the latter's experienced staff then managed to use as the basis for the production of nylon stockings.

Benefits of the plastics platform

The plastics platform offered a number of benefits to the plastics processing industry. First of all, manufacturers were able to make use of the scientific expertise at the heart of the platform. Both the plastics and the machines used for processing them became increasingly more knowledge-intensive. Moreover, discussions about the type of plastics and machinery that were required were invariably accompanied by a transfer of knowledge between the parties involved. The result was a mutual sharing of information and experience, in which the plastics processors contributed their knowledge of

A factory worker in the Netherlands inspecting nylon stockings in the 1950s

products, production technology, markets and consumers. Information on risks and costs was also shared. Generally speaking, the processing of plastics did not require any university or higher education qualifications. At the same time, steps were taken to set up courses in construction with plastics.[25] 'In reality, plastics processing remains in certain respects more of a craft than an industry,' was the judgement of the trade journal *Plastica* in 1966. '...If this situation is to improve, higher qualified technical staff will need to be employed in the production plants. ... Although there is a sufficient supply of people with the right technical qualifications, they tend to conglomerate in laboratories, particularly those operated by producers of raw materials.'[26]

There was nothing new about technology platforms. They were also around when the steam engine made its entry in the 19th century and when the first electric motor appeared on the scene in the early 20th century. They are still relevant today, playing a role in the development of Linux-based software, in the emergence of 3D printing for product design and manufacture, and in the development of apps for mobile applications and services.[27] They enable a wide range of parties – not just researchers and manufacturers, but also traders, customers, users and consumers – to contribute to the development of a particular technology, to set up new businesses with the aid of the new technology, and to innovate with standardised technologies and building blocks allowing some degree of tweaking.

So what lay at the heart of the plastics platform in the Netherlands? Underpinning the platform was an ability to produce plastics. This is how *Plastica* described the situation in 1952: 'That's why it's so important that the greatest possible quantity of raw materials is produced in our own country, given that the manufacturers are generally fully acquainted with the properties of their products and that it's much easier to work in close collaboration with the manufacturers ...'[28]

This was a view endorsed by the Dutch government, which supported the plan conceived shortly after the war for setting up a single, big, national plastics group.[29] It was during this period that AKU, DSM (at that time 'the Dutch State Mines'), Shell and Philips got together to discuss ways and means of implementing the plan. When the talks failed to produce any concrete action, Shell decided to go it alone, DSM and AKU agreed to join forces, and Philips concluded that plastics and other chemical activities did not form part of its core business.

The following sections take a closer look at the three main Dutch plastics producers, i.e. DSM, Shell and AKU. The question is: how did they come to master the technology and learn to produce plastics?

We will also be taking a detailed look at the research activities at TNO, the Netherlands Organisation for Applied Scientific Research. TNO was then – and indeed still is today – the country's biggest independent contract research centre and played a vital role in the accumulation of knowledge on plastics. The chapter concludes with a brief analysis of the role played by the universities.

DSM: the company that changed itself [30]

In 1973, the Dutch State Mines decided that they would henceforth be known by the abbreviated form of their name: DSM. This coincided with the closing of the last of the Dutch coalmines, thus ending the company's association with mining. That was not the only reason for changing the name, however. The main reason was that, over a period of 40 years prior to then, the company had undergone a successful transformation into a chemical company.

Coal mining in the Dutch province of Limburg, November 1945

The Dutch Minister of Economic Affairs, Joop den Uyl, announces the closure of the coal mines in the Netherlands, 17 December 1965.

This transformation had taken place in two stages. During the decade before the Second World War, the company had started producing fertiliser alongside coal and coke. It then built up its own plastics division during the three decades after the war. This was a tremendous achievement, due largely to the work of a generation of ambitious chemists, mechanical engineers and physicists – people like Gé Berkhoff, Jan van Aken, Dick van Krevelen and Leen Revallier. They had to fight their way into an industry that was heavily dominated by corporations from the US, Britain and Germany, all of which had a long and varied history in the chemical business.

'Very interesting!' was what Frits van Iterson, the Technical Director of the Dutch State Mines, wrote in 1939 in the margin of a technical report on synthetic fibres. '…Every big chemical company ought to make raw materials for synthetic fibres.'[31] Although the war prevented DSM* from making any progress in this area, the spotlight swung back to synthetic fibres immediately after the war. DSM set its sights on caprolactam, as a raw material for nylon, although it added other raw materials to its wish list in the 1950s. The company also started to produce plastics itself, mainly polyethylene, synthetic rubber and melamine. Let's take a closer look at the research DSM performed into caprolactam in order to gain an impression of the complexity of such a route.

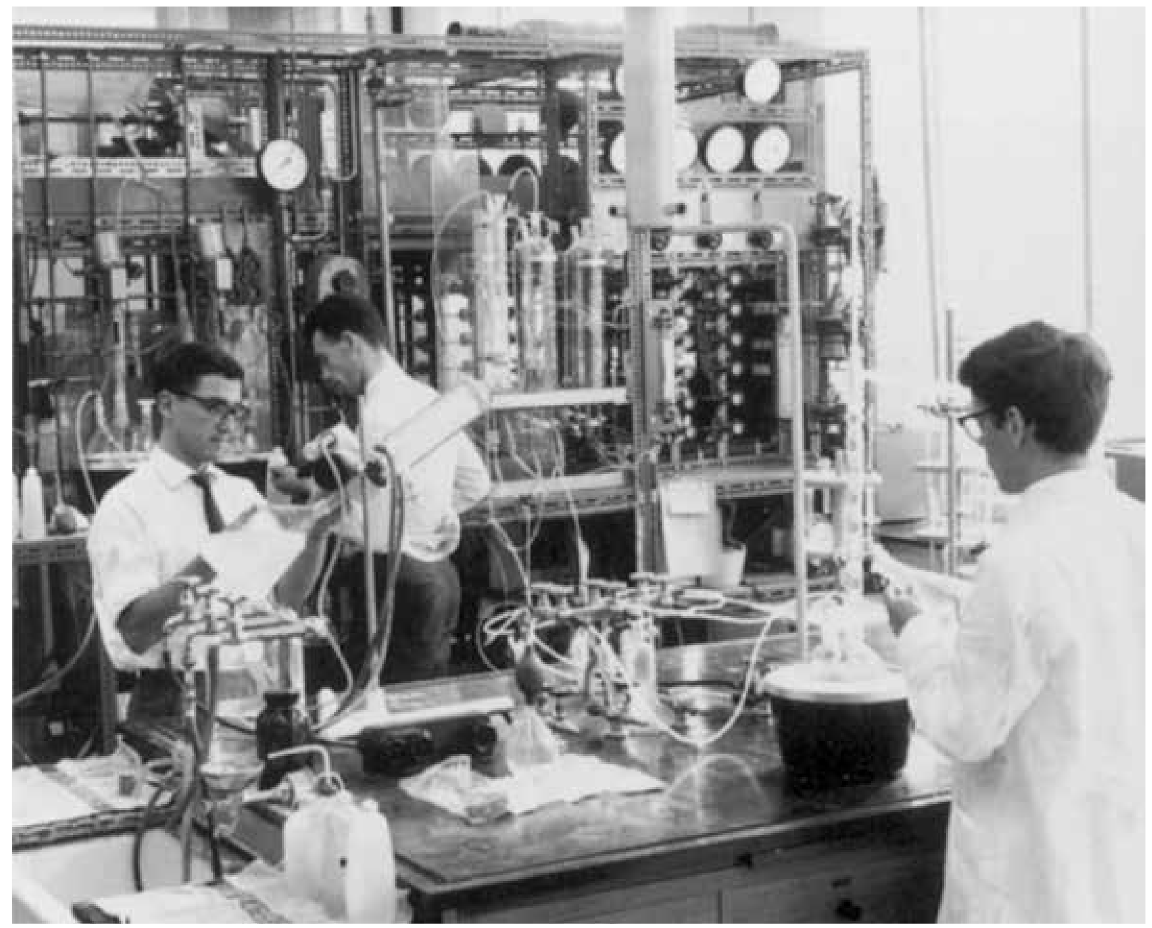
The caprolactam route

In 1942, AKU asked DSM whether the latter would be prepared to join forces in the production of synthetic fibres. DSM's initial response was non-committal: it wanted to wait until the war was over before making any move. In 1946, however, DSM contacted AKU again and talks began on how to proceed. AKU was keen to take up production of nylon 66, which was patented by DuPont. At first, however, DuPont was reluctant to grant a licence. This changed when anti-trust legislation was adopted in the US. DuPont was now willing to grant a licence, but without any technical assistance to go with it and without involving DSM in the equation. Whereupon AKU signed a contract with DuPont, but without DSM. At the same time, AKU formed an alliance with DSM in embarking on another route for the production of nylon. This route involved the use of a monomer called caprolactam, that DSM would produce and which AKU would then polymerise and process into nylon 6.[32]

** We will refer to the company in the remainder of this book by its present name, i.e. DSM, given that the focus is on its chemical activities.*

The caprolactam route had two big advantages. First, it was a good way of circumventing the patents held by DuPont. Secondly, the basic expertise that was needed was already freely available – given that IG Farben and a number of other German companies had already discovered the route. Thanks to the German reparation payments, both the patents and the technical reports were freely available after the war, thus allowing both AKU and DSM to profit from the huge potential for innovation that the German chemical industry had built up over many decades.[33]

And so it was that DSM began performing research into caprolactam in 1946. It had set up a 'Central Laboratory' shortly before the war, which was now responsible for all research activities involving coal and fertiliser. The lab had a staff



The polymer research department of DSM's Central Laboratory in the 1950s. The department played an important role in the introduction of new polymers.

The phenol plant opened by DSM in 1952 was based on the Tyrer process. Due to production problems the plant had to be closed in 1955.

of just under 200 at the end of the war. Apart from the Central Laboratory, DSM also operated a number of pilot plants where processes could be scaled-up and products could be tested. By around 1950, more than a quarter of the research activities at the Central Laboratory revolved around the preparation of caprolactam.

One of the routes for making caprolactam began with phenol and used the following route to produce caprolactam: cyclohexanol → cyclohexanone → cyclohexanon oxime → crude caprolactam → pure caprolactam. For each of these steps, choices had to be made, studies performed, pilot plants designed, processes optimised and products tested. It was not all smooth sailing, however. Take, for example, the choice DSM faced with regard to phenol: to buy it on the open market or produce it in-house. The in-house production option was an attractive one, given that phenol could be extracted from benzene, which was in turn readily available as a by-product of coke production. Moreover, DSM had another possible application for phenol: it could also be used in the production of synthetic resins.

DSM's phenol plant

In the event, however, the construction of a phenol plant proved to be a disaster. The conventional production process did not work, as it generated large quantities of undesirable by-products. Although DSM obtained an exclusive licence for an improved production process, this process had not yet been tested on an industrial scale. So the researchers at the Central Laboratory concentrated all their efforts on scaling it up – sadly, to no avail. Despite the fact that both a pilot plant and a fully-fledged production plant were built, the production process proved so complex that there was no way of producing phenol in a reliable and profitable manner. The suggestions made by DSM's researchers for altering the plant in order to solve the technical problems had very little effect and, in 1955, DSM decided to close down the plant and buy phenol instead.

Nonetheless, DSM remained interested in producing phenol in a plant of its own. To this end, the company explored the possibility of working together with external partners. After due consideration, DSM decided that Dow Chemical,

which had designed a production process of its own, had the best papers. The partnership offered other new opportunities, as the US company was also interested in the caprolactam-based production route for nylon 6, which meant that there was plenty of scope for knowledge-sharing.

Unfortunately, the construction of the joint production plant was plagued by big delays. And when the price of phenol collapsed, the two partners faced the prospect of severe losses on the production plant. Dow Chemical made it clear that they wished to withdraw from the project and, in 1964, the plant acquired the status of a wholly-owned DSM subsidiary. The name was changed from *NV Staatsmijnen-DOW Fenol* to *Chemische Industrie Rijnmond* ('Rijnmond Chemical Industry') at the same time.[34]

Most experiments were not quite as dramatic as that with the phenol plant, although it was by no means an easy ride. Starting in 1948, the situation was as follows. DSM had built a pilot plant for the production of caprolactam. Four years later, the plant began producing caprolactam on an industrial scale, with a limited capacity of 3,600 tonnes per annum. However, all process steps needed to be improved. Production yield needed to be increased, with fewer undesirable by-products, and the technical bottlenecks needed to be resolved. The product also needed to be purer, as the quality of the caprolactam was the main determinant of the quality of the nylon.

In-house research

If DSM was to master the caprolactam production routes and all their process steps, it was absolutely vital that it should perform its own research. To carry out the broad-based research programme that was required, the Central Laboratory mobilised all the available expertise from the various groups at its disposal – including inorganic chemistry, catalysis and analysis. There was a semi-technical department at the lab, as well as a pilot plant for dealing with the countless problems with equipment and scaling-up. The lab also had its own service department, which was initially known as the 'Spinning House' but was later rechristened as the Fibre Intermediates department. The staff of the department tried to solve problems encountered by customers. Help was also provided by other DSM departments: for example, the works laboratory at the 'Organic Pilot Plants' was closely involved in the studies into the purification process.

In-house research was not enough in itself, however. Success was not achievable without close cooperation with other companies. The Central Laboratory had links with many other companies, some of them sporadic and others more systematic. These external partners included AKU (Netherlands), Dow Chemical (US), Holtzverzuckerungs AG (Switzerland) and Montecatini (Italy). DSM bought and sold licences, and signed cooperation agreements. Research into the caprolactam routes was fairly open, with many different companies willing to exchange, buy and sell expert knowledge. There were just two basic requirements: DSM

In 1963, DSM started construction work on a melamine plant. The buildings of the company's Central Laboratory are to be seen in the background.

should be a relatively equal partner and it should have something to offer in return. The Central Laboratory managed to build such a position.

With an output of 100,000 tonnes in 1966, DSM had become one of the leading producers of caprolactam. It was a tremendous achievement. And yet there was no time for anyone to rest on their laurels. Of the total output, only 73,000 tonnes were sold. Prices fell and soon began to draw near to the cost price. BASF and Bayer were both planning to step up their output of caprolactam. Higher production had resulted in a sharp increase in the volume of ammonium sulphate, a by-product that was not always easy to sell. Finally, keen as they were to produce more nylon 66 in Europe, both ICI and DuPont had stepped up their technical services for customers.

In short, the scene was set for more heated competition between caprolactam-based nylon 6 and 'conventional' nylon 66. If DSM was to retain its market share, it would have to come up with further innovations in caprolactam.

Gentlemen's agreement

Right up to the mid-1950s, caprolactam (the raw material for the production of nylon 6) and nylon salt (the raw material for conventional nylon, i.e. nylon 66) were the Central Laboratory's main objects of research. However, DSM's aim was to be more than just a supplier of raw materials for the production of plastics. It was keen to start producing plastics itself, but realised at the same time that it needed to tread carefully. While the polymerisation of caprolactam would be the first step in the right direction, there was a tacit understanding that this was the preserve of AKU. DSM informed AKU in 1957 that it was planning to ignore this gentlemen's agreement. This particular road to plastics production was now open.

DSM had another card up its sleeve. The company had another line of business, which was the production of fertiliser. The raw material used to produce fertiliser was urea, which could also serve as the base material for melamine. Like Bakelite, melamine was a thermosetting plastic; it was crystal clear and easy to dye – which was an advantage compared with the dark-brown Bakelite. After some study, DSM decided in 1963 to build a production plant with an annual capacity of 10,000 tonnes of melamine. In the event, such was the success of the product that it was decided just a few years later to quadruple the plant's output.

DSM also had access to another in-house raw material, i.e. ethylene, a by-product of coke production. This presented DSM with an opportunity to produce polyethylene, a thermoplastic with huge future potential. It was this interest in polyethylene (PE) that resulted in one of the biggest research programmes the Central Laboratory carried out in the 1950s and 1960s.

Polyethylene

Polyethylene had been invented by ICI, which was a big patent holder and which had developed a reliable production process. Production took place in extreme conditions – a very high pressure of between 1500 and 2000 atm. Getting a licence from ICI was not easy, but DSM eventually managed to acquire one. In 1957 DSM, in close consultation with ICI, built a plant with an annual production capacity of between 7,000 and 10,000 tonnes of polyethylene.

Another production process had been developed in previous years, however. In 1953, Karl Ziegler of the *Max Planck Institut für Kohlenforschung* had succeeded in making polyethylene with the aid of special catalysts at atmospheric pressure. The properties and applications of this low-pressure PE differed from those of high-pressure PE. In this new process, metal catalysts were used to produce totally unbranched polyethylene, i.e.

consisting of very long, straight chains. This was unlike the old process, in which ethylene molecules were randomly attached to each other in a branched pattern. The unbranched polyethylene produced with Ziegler's catalyst had a relatively high crystallinity, which meant that it had better thermal and mechanical properties.[35]

In 1955, DSM decided also to acquire a licence to use the Ziegler process. However, having a licence did not mean DSM could implement the Ziegler process straightaway. It had only been tested in the lab, and the problems to be resolved in scaling-up the method from lab to semi-technical scale, and then on to a pilot plant and industrial scale production, were simply enormous. It was not until 1962 that production of low-pressure PE could finally get underway in a production plant with the same capacity (7,000-10,000 tonnes per annum) as the high-pressure PE plant built earlier.

Synthetic rubber

The research on PE was among the Central Laboratory's major undertakings, but not its biggest. That distinction goes to the synthetic rubber programme, based on previous research by Ziegler and the Italian chemist Giulio Natta. One of the outcomes of their studies of new catalyst systems was the synthesis of polymers that were very similar to natural rubber. In 1955, the Central Laboratory quickly picked up the basic ideas underlying the principle and started experimenting with catalysts that were covered by the existing Ziegler licence. The first batch of synthetic rubber, known as EPDM rubber, was produced in a pilot plant in 1962. Industrial-scale production began five years later.

The same strategic challenges

These plastics threw up the same type of strategic questions as had occurred in the case of caprolactam. How, for example, should one choose from the many attractive production routes, and from the wide variety of plastic products? Who were the ideal partners for the Central Laboratory? What was the better option – buying a technology or developing it in-house? Which patents offered the best prospects? How strong was DSM's own patent position? And so the questions continued.

The answers tended to vary, of course, depending on the plastic in question. In the case of high-pressure PE, DSM had bought the technology from ICI and there was hardly any need for in-house research. What was needed, however, was the competence to adopt the technology. In the case of low-pressure PE, it had been necessary to conduct a full programme of in-house research and subsequent scaling-up. These were high-risk routes that took many years – in some cases more than a decade – to complete.

As a part of this process, full attention also needed to be given to the applications. The plastic had to be tested and its composition had to be described. Customers needed information on the plastic's properties, its behaviour in the machines, and the characteristics of the end product. There

Sample taking in DSM's caprolactam plant

A researcher at AKU's synthetic fibres pilot plant examines the cross-sections of fibres under a phase-contrast microsope.

were special units at the Central Laboratory that dealt with these matters – units such as the Spinning House and the Plastics Technology department. In short, what was needed in order to sell the product was a knowledge of applications and customer service.

AKU and Akzo: searching for their future roles

Based in the eastern Dutch town of Arnhem, the international AKU group was one of the world's biggest producers of rayon, or artificial silk. Rayon was a semi-synthetic viscose fibre made from cellulose. DuPont's discovery of nylon 66 posed a direct threat to AKU's market share. AKU's claims that a rosy future beckoned for viscose fibres – and which it continued to make until late in the 1950s – were in fact made against its better judgement.[36] DuPont had already substantially stepped up its production of nylon. Nylon was now being produced by a range of companies in Western Europe, Eastern Europe, the US and the Far East.

At the same time, studies were also underway into other types of fully synthetic fibres. ICI bought the rights to a polyester fibre with a high melting point. The German chemical company Bayer was looking into the possibility of using acrylic fibres as a wool substitute.[37] DuPont and the Italian firm Monsanto were also interested in this type of fibre. Polypropylene fibres were developed in the late 1950s by various companies including Montecatini, an Italian firm, and Hercules, a US company. DuPont also managed to devise a process for spinning polyethylene fibres. Synthetic fibres had all sorts of applications: they were used not only in clothes and floor coverings, but also for other purposes such as ropes and car tyres. The question was: was AKU capable of standing up to these international giants? One thing was clear: success would depend on its research capability.

The research labs at AKU

AKU's research infrastructure in the Netherlands dated from the 1920s (see Chapter 2: The events leading up to the plastics revolution).[38] The research facility in Arnhem was responsible for developing, testing and approving viscose fibres and the raw materials needed to produce them. The activities were distributed over a number of laboratories. There was the Physics Laboratory, for example, which tested the elastic properties of tyre cord fabric, a product that was designed to strengthen a car tyre carcass and which had gone into production at AKU in 1949.[39] The Textile Lab accommodated a department that housed the most commonly used textile machines, which the researchers were able to use to test the quality of the viscose fibres from the production plants. These tests acted as an additional quality check

Plastics: platform, research and development

over and above the routine checks performed by the works labs at the plants themselves. The Textile Lab also produced prototypes of new product variants, as well as samples that the sales team could use to demonstrate the properties of both new and existing products to prospective customers.[40]

There was also a research department known as the Institute for Cellulose Research. Founded in 1941, this was located in Utrecht, at some distance from the production site in Arnhem. The thinking behind this was that this would prevent the researchers from being bothered with practical problems from the plant.[41] The institute's research activities covered a wide area and ranged from in-depth studies aimed at acquiring new knowledge to short-term projects designed to generate practical results.[42] The institute was headed by Petrus Hermans, who had previously been employed by *Hollandse Kunstzijde Industrie* ('Dutch Artificial Silk Company', better known as HKI), where he had gained wide experience thanks to the time he had spent in both production and research.[43] The institute was a breeding ground for talented researchers and one of the major suppliers of university professors (see Table 4.1). In 1952, Hermans decided that it should henceforth focus on fully synthetic fibres.[44]

All in all, the AKU research labs employed a workforce of around 530 in 1950, a figure that was to double during the course of the decade, so that, by 1960, the workforce totalled 1,075 (including the pilot plant but excluding the works laboratories at the production plants).[45]

Diversification strategy

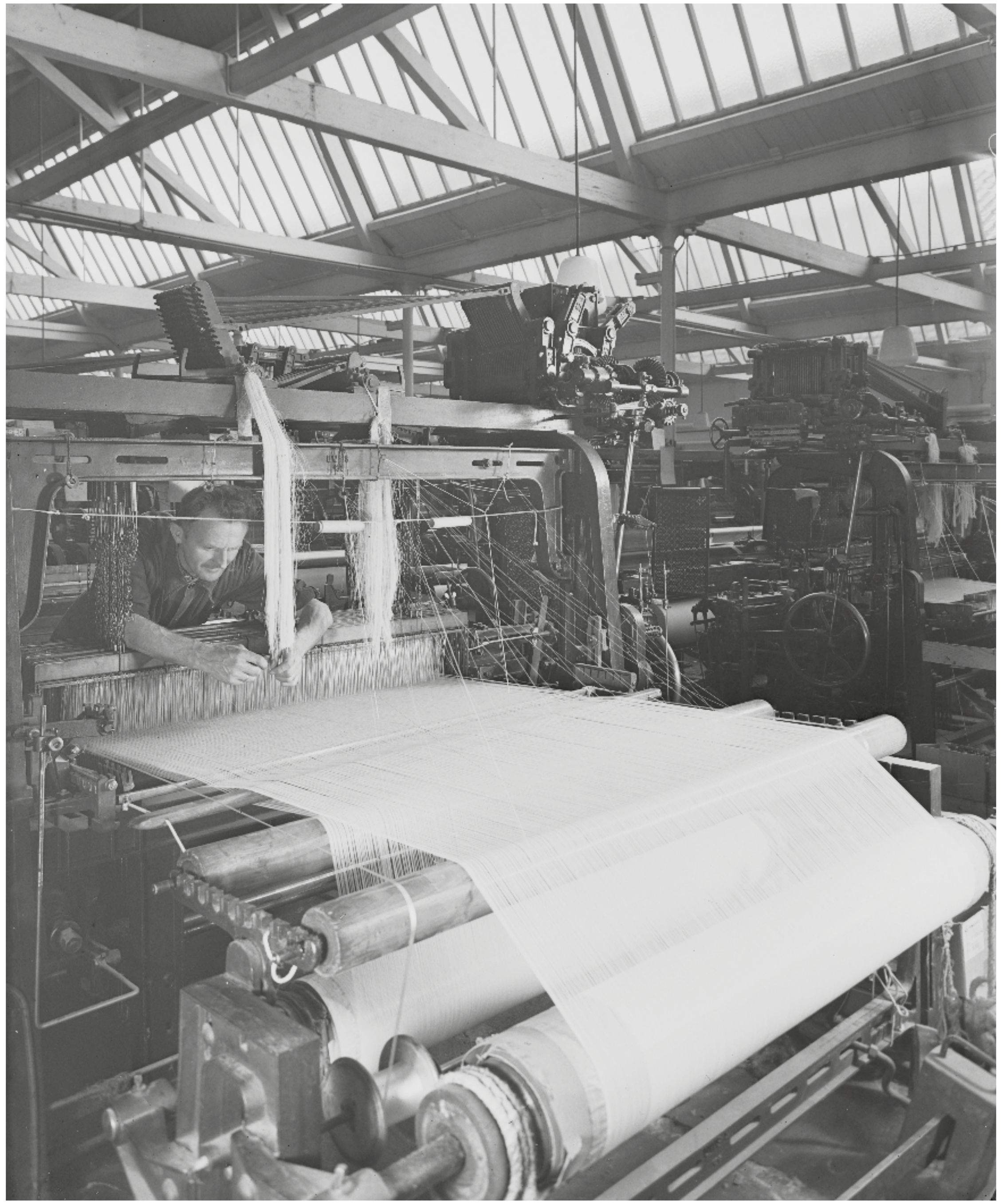
What sort of strategy did AKU pursue in order to acquire a share of the market in fully synthetic fibres? Having already acquired a licence from DuPont to produce nylon 66, AKU then joined forces with DSM to develop a caprolactam-based route for the production of nylon 6. A nylon research programme was launched. However, the idea was not to use nylon exclusively in textile applications: AKU was keen to diversify and become less dependent on the ups and downs of the business cycle in the textile industry by developing a 'second leg', to use the term coined by Jo Meynen, one of AKU's board members at that time.[46]

Thus, AKU introduced its Akulon brand of nylon grades and tried to build up a market for them in the plastics processing industry. One of the products was Akulon for piping, whose market introduction was beset with problems, however. The Akulon had to be heated during the production of the pipes and subsequently cooled so that both the wall thickness remained consistently equal and the pipe itself remained consistently round. AKU's researchers were also initially stumped by the difficulty of producing large-diameter pipes.

Most of the problems had been resolved by early 1955, however, so that AKU was now in a position to get in touch with a big shipbuilding and engineering company called Bronswerk. Akulon pipes had the advantage for the shipping industry of being lightweight and AKU persuaded Bronswerk to give them a try. Trials were also performed with Akulon piping in the house-building industry. Sadly, neither of these experiments were successful. Compared with high-volume plastics such as polyethylene, the market for Akulon was relatively small. Nonetheless, it was a market in which Akulon's specific properties, such as a high melting point and a low relative density, were to prove advantageous.[47]

Formation of Akzo

AKU's strategy of diversification was not particularly successful and, by the end of the 1960s, sales of synthetic fibres accounted for 97% of turnover.[48] AKU was scarcely represented in



The AKU plant in Nijverdal (Netherlands) in the 1950s

other segments of the plastics market. In 1969, AKU merged with *Koninklijke Zout Organon* ('Royal Salt Organon') to become part of a chemical and pharmaceutical group that was to be known as Akzo.

Akzo was the biggest producer of synthetic fibres in Western Europe. This was a market in which AKU, as one of its constituent companies, had succeeded in developing a wide range of products. AKU had a big share of the market in industrial fibres in particular. It became clear at the beginning of the 1960s that this was a boom market. Not only that, it was also less susceptible to the fluctuations seen in the textile and floor coverings markets. Competition was fierce, however, forcing Akzo to defend its share year in, year out. This is illustrated by Akzo's battle with DuPont over a super-strong, super-elastic fibre.

In 1968, DuPont announced the discovery of a polyamide fibre, the properties of which

it had no hesitation in describing as being 'superior'.[49] Combining exceptional strength with extraordinary elasticity, it was regarded as being 'as strong as steel and as flexible as rubber'. No one beyond the walls of DuPont knew what it was made of. Initially styled 'fibre B', it was later to be marketed under the brand name of Kevlar. The quest for a super-strong fibre was primarily the result of advances in car tyre technology. One of the materials used in the production of traditional car tyres was rayon, or artificial silk. As one of the main manufacturers of this semi-synthetic fibre, DuPont realised that the emergence of new, radial tyres (tyres that were reinforced with steel) spelled the end of its market. The new tyres were both safer and more durable. Kevlar, it was thought, would prove an effective alternative to steel.
Akzo was also one of the world's biggest manufacturers of rayon tyre yarns. Keen to challenge DuPont on its home ground, it decided to launch a study into the composition of Kevlar. It was apparently led by its mission: 'Our main purpose is to show the outside world that Akzo can do just as it likes without any problems.'[50] The project team, which was headed jointly by Dick van Krevelen, who had moved to Akzo from DSM, and Frans van Berkel,[51] realised that it was a high-risk enterprise that would inevitably lead to a confrontation with DuPont over patent rights. The team hoped to first discover and then patent original features on the route to Kevlar, thus allowing them to start negotiations with DuPont on these features and eventually obtain a licence. Although Akzo had a huge amount of ground to make up, it decided to challenge DuPont. (See also Box 7: 'The Battle for Twaron')

With both newcomers like DSM and established rayon manufacturers like AKU finding it tough to acquire a substantial share of the plastics market, how did Shell fare as the third Dutch company at the core of the plastics platform? Shell was also a newcomer, but had access to a vital raw material for the production of plastics in the post-war era: petroleum.

Shell: the chemical complex[52]

Shell was in a similar position to DSM. It was neither a plastics producer nor a plastics processor by origin. It was an oil company that used its raw material for the primary purpose of producing fuel. However, it had become clear at the end of the Second World War that petroleum was an excellent platform for producing plastics and the various feedstocks needed for their production. The question facing Shell, therefore, was: should it now move into this new chemicals branch?

After a lengthy debate among the company's top management, Shell decided in 1947 to move into the petrochemical industry in the Netherlands, using its refinery in the Rotterdam district of Pernis as a springboard.[53] Between 1945 and 1960, Shell invested around EUR 550 million in the construction of a huge chemical complex. The refinery grew into the biggest in Europe and indeed one of the biggest in the world. It produced massive quantities of ethylene, propylene, butylenes and various other materials, which were used as a basis for producing all manner of intermediates and end products with a higher added value. Shell's Pernis operation thus evolved into a fully integrated production complex where product flows were progressively upgraded. The end products were sold throughout the European market.

Process of expansion

One of the main activities of Shell's petrochemical arm was the production of plastics, resins and rubbers.[54] A series of production plants quickly came on stream, including a PVC factory in 1950, an epoxy resin factory three years later, and in 1963 a factory producing synthetic rubber (styrene-butadiene rubber, otherwise known as SBR rubber). The latter plant had a production

Oil terminals at Rotterdam Europoort (Netherlands) in the 1960s

capacity of 50,000-60,000 tonnes a year and represented a new trend in the chemical industry: expansion of scale. For example, Shell joined forces with the Italian company Montecatini in 1963 to set up a joint venture – Rotterdamse Polyolefinen Maatschappij (RPM) – for the production of polypropylene. The company was 60%-owned by Shell, with Montecatini holding the remaining 40% of the share capital. RPM was later to become one of the world's biggest producers of polypropylene.

A similar development was to be seen in the production of PVC. This was also a period in which Shell built factories for the production of polybutadiene and isoprene rubber. The trend towards expansion of scale in the production of plastics and other end products meant that a parallel process was required in the production of raw materials. Two paraffin cracking units and a naphtha cracker were built, capable of producing a total of 135,000 tonnes of ethylene, 90,000 tonnes of propylene and 25,000 tonnes of butadiene on an annual basis. By the early 1970s, however, Shell had exhausted the potential for expansion offered by the site in Pernis. The next step was therefore to build a new chemical complex and the location chosen was a town just south of Rotterdam called Moerdijk.

Another Shell activity that should not go unmentioned here is the development, in the 1950s, of a high performance elastomer called Kraton. The R&D work on this so-called styrenic block copolymer was undertaken by Shell both in the Netherlands and at the labs of a company that it had just acquired in the US. Kraton proved to be a great success in applications such as shoe soles and for example as a bitumen modifier that enhances road surface durability. In 2001 Shell divested this business, which now operates under the name Kraton Corporation.

Partnerships

Shell's transformation was built largely on a number of partnerships with chemical companies. By 1972, Shell had invested GBP 562 million (worth just over EUR 2 billion today) in chemicals activities. Of this amount, GBP 200 million (or around EUR 730 million) was invested in companies in which Shell owned a shareholding of at least 50%. Operating in this manner enabled Shell not just to share risks, but also to limit the amount of capital tied up and to gain access to specific areas of expertise.

Back in the early 1950s, Shell was already producing polyethylene in close partnership with BASF. We have already referred to the joint venture with Montecatini for the production of polypropylene. In the early 1960s, Shell also acquired 51% of the shares in Wavin, a Dutch manufacturer of PVC pipes.

Shell also had a policy of buying external expertise. This it did, for example, with epoxy resins, buying both American know-how and American technology.[55] And of course, Shell also had its own laboratories, where products and processes were developed and improved. For example, the Shell laboratory in Delft was given the task of performing research into plastics and rubber. Shell itself claimed in 1960 to be a world leader in chemical research.[56]

Big losses

Plastics were the fastest growing branch of Shell's petrochemical business. The plastics business included not only the production of raw materials for plastics, resins and rubbers, but also the processing of plastics into products such as PVC pipes. However, the results of all these efforts were to prove rather disappointing, particularly on the plastics front. The plastics, resins and elastomers product group remained heavily loss-making right up to the end of the 1960s. The only truly profitable product was epoxy resin. In 1968, the product group chalked up its first – albeit modest – profit, thanks to the resins and the elastomers. Plastics were still deep down in the red. So what was the underlying problem?

Those in favour of investing heavily in the petrochemical industry claimed that a combination of low earnings and losses was the inevitable consequence of rapid growth. It was simply a question of patience – waiting for payback time. Big investments were needed in order to finance the growth that would produce the expected returns in due course. Several decades later, Shell's historians were to write: 'Investing in bulk production meant that Shell could remain optimistic by taking the conventional long-term view. Only a very small number of commercial firms could be so upbeat about investments that took over a decade to generate a good return.'[57]

The poor results were also ascribed to the cyclical nature of the plastics business. The petrochemical industry also suffered, it was claimed, from low entry thresholds and an excessive sense of optimism. Overcapacity, rock-bottom prices and tiny margins were the order of the day. Although this was a recurring situation – seen on a number of occasions in both the 1950s and the 1960s – it is not in itself a sufficient explanation. Despite being in the same situation, both DSM and AKU succeeded in posting profits.

VCM and chlorine

One pressing problem for Shell was the supply of raw materials for the production of plastics, PVC in particular.[58] This may sound a strange thing to say in relation to an oil company, but it was simply the case that the production of VCM (vinyl chloride monomer, used to produce PVC) required large quantities of chlorine. Chlorine was also an important component in other petrochemical processes.

Shell was initially supplied with liquid chlorine by train, by a firm called *Koninklijke Nederlandse Zoutindustrie* ('Royal Dutch Salt Industry', or KNZ) from its Hengelo site. However, these chlorine supplies were far too small to meet Shell's needs. The situation improved when KNZ stepped up the production of chlorine at its other sites and other firms also started to produce more of it. Shell's attempts to develop its own process for the production of chlorine miscarried, however. Not only was the process too expensive, it was also beset with corrosion problems.

The production flows at KNZ's and Shell's operations in the Botlek industry complex of Rotterdam gradually became intertwined with each other: Shell sold hydrochloric acid to KNZ, which used it to produce VCM, which it then supplied to Shell as a raw material for PVC. However, Shell's continued dependence on other companies for the supply of chlorine (and VCM) remained the weak link in the chain.

Overconfidence?

It is also possible that Shell's researchers and lab management overrated their own abilities.[59] Emotion was an important factor in this. Shell was a technical and scientific company whose engineers and scientists were tremendously interested in developments in the petrochemical industry. It was a field with major scientific and technological challenges that needed to be addressed. Shell boasted top-quality competences, a worldwide network and sufficient capital resources of its own. Not without a certain degree of arrogance, Shell reckoned that it was capable of rising up to 'any challenge of any kind, anywhere in the world'.[60]

However, another key requirement for those operating in the plastics market was a readiness to meet the wishes of customers all over the world and to supply products that met their specifications. Successful companies like DSM and AKU expended a great deal of energy on providing technical and commercial support to customers. Whether Shell was sufficiently customer-minded is something of a moot point.[61]

The TNO Plastics Institute: a national knowledge centre[62]

DSM, AKU and Shell each built up their own separate knowledge infrastructures, geared towards their own specific activities in plastics. This clearly benefited the customers of each of these companies, who were able to access information on the various types of plastic as well as advice on how best to use them, and who were able to buy plastics that met their specific requirements. At the same time, TNO (the Dutch Organisation for Applied Scientific Research) was seeking to create a national knowledge infrastructure for the plastics industry as a whole.

Roel Houwink: a crucial role

The groundwork had already been laid during the Second World War. Plastics were a hot topic in industrial-chemical circles in this period,[63] when a symposium on plastics attracted no fewer than 300 delegates. Roel Houwink was one of the leading figures during this period. Apart from being a chemical engineer working for the Vredestein tyre company, he was also a technologist at the National Rubber Institute, and the Technical Director of the Philite factory, where Philips produced its Bakelite material. In 1939, he was appointed director of the Rubber Foundation, a role in which he championed the use of plastics. Houwink wrote two authoritative books on plastics, which were published in 1939 and 1943.[64]

In 1942, Houwink was appointed to an unsalaried lectureship in 'Chemistry and Technology of Macromolecular Substances' at Delft University of Technology.[65] This meant that he was the first academic researcher whose field of research covered not just conventional rubber, but also the new synthetic plastics. He launched a research project on synthetic plastics and was the driving force behind the creation of the Plastics Institute, which became part of the TNO group after the war. Houwink later became a board member and the temporary director of the TNO Plastics Institute, as it came to be known.[66]

Roel Houwink was also the spiritual father of a national knowledge infrastructure with a special emphasis on science, technology, knowledge transfer, public education and training. English translations of his manuals on plastics were produced, including *Elastomers and Plastomers, their chemistry, physics and technology* (1948) and *Fundamentals of synthetic polymer technology in its chemical and physical aspects* (1949). Houwink went on research trips to both the UK and the US, and was not only a driving force behind the creation of the *Journal of Polymer Science*, but also one of its editors. The journal soon grew into a leading scientific journal for research into plastics.

Houwink was also keenly interested in the practical aspects of the plastics industry. He initiated an extended course on plastics and was also involved in the launch of a technical journal called *Plastica* in 1948 that was edited by staff from the TNO Plastics Institute (and owned by TNO for some considerable time). *Plastica* became the journal of choice for plastics manufacturers and processors. In short, under Houwink's leadership, the TNO Plastics Institute energetically set about creating an infrastructure that was capable of promoting research, industrial operations and the public use of plastics in the Netherlands.

Scientific Research department

The TNO Plastics Institute consisted of four departments: the Scientific Research department, the Industrial Research department, the Testing department and the Public Information department. The Scientific Research department performed research that is perhaps best described as 'mission-centred'. It had three principal aims: to foster a better understanding of plastics, to develop potential future applications and to serve the interests of society at large. For example, due to the shortage of raw materials in the wake of the Second World War, the department investigated the possibility of using potato flour as a raw material for the production of plastics. The study painted a clearer picture of the structure and properties of the components of potato flour, thus creating opportunities for the industrial production of new plastics.

Not long after this, the department turned its attention to fully synthetic plastics. Its study of phenol formaldehyde resin (used as the basis for Bakelite) is a good example. The study centred on devising a means of quantifying the relative quantities of the first products of the condensation reaction. Once this had been done, the next step was to find additives that had a strong influence on the balance of these products, and develop resins with a shorter setting time and a non-conventional structure.

The department also spent a lot of time on improving research techniques. One of the projects on which the researchers spent many years was a painstaking study of how to measure the viscosity of solutions, one of the fundamentals of plastics research. The findings

The library at DSM's Central Laboratory

helped to improve both viscometers and methods of calibration. While a small proportion of the department's research activities was funded by industrial companies, the bulk of the funding came from TNO's general resources. In 1954, the department was subsumed into a new unit known as the TNO Central Laboratory.

Industrial Research department

The Industrial Research department also performed research, but it did so on a commissioned basis. It was made up of a number of sub-units or sections, including a reinforced plastics section, a spinning section and a pilot plant. Its research activities were closely related to industrial practice. For example, the pilot plant had a big space containing the most commonly used machines for the pre-processing and processing of plastics. Various machine manufacturers and importers lent out machines for the plant to use in its trials.

Although the department also bought new machinery, it was not feasible to thoroughly explore all the machinery and equipment available on the market. For this reason, the machines used by the department represented just a small part of what was available. After all, there were more than 90 manufacturers of injection moulding machines around the world – to give just one example – each with its own series of models. Against this background, the department staff made sure that they had as much documentation as possible on all machines. This enabled them to advise clients on matters such as choice of machinery, mould design and processing conditions.

Testing department

The Testing department's job was to find out whether a given plastic product met the relevant specifications.[67] The staff tested all sorts of intermediate products such as moulding powders, laminates and foams, as well as end-use products such as nappies, tow lines for ships, shoe soles and floor coverings. A major part of their work was determining the mechanical, electrical and chemical properties of plastics.

Developing new testing methods was another important activity. Although the plastics industry sourced many of its testing methods from the metal industry, the highly specific nature of plastics technology meant that the industry also needed certain testing methods of its own. Testing methods also played an important role in the standardisation of plastics. Tests and standards were a matter of public interest. They helped to reassure processing companies about the quality of the products supplied to them by their suppliers and also meant that the same companies knew exactly what requirements their end products would have to meet in order to be sold on the open market. Standardisation also helped to boost the efficiency of production processes. On the consumer side, standards helped people to know what to expect from the plastic products they bought, especially with regard to their health and safety aspects.

TNO was a key player in all this. Its researchers were strongly represented on the standardisation committees, working parties and policy-making committees of the Netherlands Standardization Institute (originally NNI, now NEN). Both its research activities (not just those performed by the Testing department but other departments as well) and, more particularly, its quality mark were absolutely invaluable.

Public Information department

The last of the four departments was responsible for public information, documentation and patents. In the mid-1950s, the Public Information department was the proud owner of a big database – probably even the biggest in the country – in the form of a library, a collection of samples and a collection of around 25,000 brochures and leaflets on raw materials, additives, intermediates and semi-finished products, mechanical aids, machines and products. It received between 4,000 and 5,000 enquiries from the public every year, ranging from simple requests for the name and address of a supplier to queries that needed to be answered by experts from one of the Institute's departments. There was also an Abstracts Service, which proved extremely popular. Finally, the department helped to organise courses, trade fairs and exhibitions. It is important to remember that information was both crucial and scarce during the post-war period. The 20 or so members of the department's staff fulfilled a tremendous need.

As far as revenue was concerned, the situation in 1955 was that the TNO Plastics Institute earned 58% of its income from contract research and 40% from government grants. A further 2% of its general resources came from voluntary contributions from the private sector. Its contract research activities in 1955 encompassed a total of 266 research assignments, many of which probably involved some form of testing. We know from the statistics that the Institute performed around 4,000 analyses in that year. Institute staff also issued around 4,300 recommendations. The obvious implication of these figures is that many of the plastics manufacturers and processors called on the institute's services for research, testing and advice.

Other TNO units also performed research on plastics. The combustibility of plastics was one of the topics examined by the TNO Centre for Fire Safety, while the TNO Fibre Institute looked into combinations of rayon fibres with plastics, and the TNO Rubber Institute worked on synthetic rubbers. TNO's status was recognised by the academic world and in a number of cases TNO research was recognised as PhD work to be rewarded with a doctorate. Bert Staverman, the director of the Scientific Research department at the TNO Plastics Institute, was given a part-time professorship at Leiden University.

A marginal role for the universities

Academia was the notable absentee at the heart of the plastics platform.[68] The universities were caught completely unawares by the revolution that was taking place. Very little academic research was performed into plastics at the time.[69] Polymer science (to use the academic name) simply did not exist as a specialist field. Although the universities supplied the academic researchers required by industry, these were not specialist polymer scientists. At best, they had been trained in related disciplines, such as organic and physical chemistry. It was the big industrial companies (AKU and DSM in particular) and TNO who were responsible for building up the universities' new area of expertise – in part to meet their own needs, of course.

The universities found themselves under pressure from all sides after the war, and not just from the plastics industry. Industry in general as well as government departments were already experiencing an acute shortage of university educated scientists. At the same time, both these sectors had decided to prioritise scientific research and step up their investments accordingly. Immediately after the war, and notwithstanding the shortage of funds, the Dutch government decided to commit new funding for research. A new organisation, 'Netherlands Organisation for the Advancement of Pure Research' (or ZWO, now known as NWO), was set up in 1950. Two new universities of technology were opened: one in Eindhoven in 1956 and another in Enschede in 1963. Across the board, public spending on education and R&D rose from around 3% of GDP in 1950 to over 8% in 1975. The big multinational companies also lent their support to the expansion of the university system. In 1946, Shell donated a sum of three million guilders to the Dutch government. This was intended to finance the construction of two pilot plants, one for chemical technology and the other for physical technology, at Delft University of Technology, as well as the modernisation of the Physical Laboratory in Leiden.[70] Philips, for its part, donated one million guilders towards the launch of Eindhoven University of Technology.

Jan Hermans: pioneer

The rise of polymer science as a university discipline formed part of this trend. The pioneering figure in this connection was Jan Hermans (or JJ, as he was generally called by friends and colleagues). Hermans obtained his doctorate at Leiden University in 1937. In 1942, when the war forced him to go into hiding, he ended up at AKU's Cellulose Institute, where his namesake, Petrus Hermans (no relative, as it happens), taught him the secrets of cellulose polymer chemistry.[71] In 1946, Jan Hermans was appointed professor of physical chemistry at Groningen University, where he initially concentrated the majority of his research efforts on the physical chemistry of polymer systems.[72] In 1953, he moved from Groningen to Leiden, before leaving for the US in 1958. He was succeeded by Bert Staverman, a physical chemist at TNO, who took up the appointment on a part-time basis.

Professorships

All 12 chairs in polymer science and technology established prior to 1970 (including both full-time and part-time professorships) were occupied by research scientists from the plastics industry. AKU was the principal supplier of professors, with five present and former AKU employees holding a total of seven (part-time) chairs. TNO followed next, with two (part-time) chairs. NYMA (an artificial silk spinnery), DSM and DuPont each supplied one (part-time) professor (see Table 4.1).

At the universities, the professors generally simply carried on with the research work they had started in their companies. In Eindhoven, for example, Derk Heikens with his AKU background, and Emile de Roy van Zuydewijn, a practical

TABLE 4.1 (Part-time) professors of polymer chemistry at the Dutch universities, by organisations of origin, 1945-1970

Name	Organisation of origin	University	Year of appointment
A. (Arnold) van Rossem	Government Information Service for the Rubber Trade and Industry	Delft	1939
J.J. (Jan) Hermans	AKU	Groningen	1946
J.J. (Jan) Hermans	AKU	Leiden	1953
C. (Carel) Koningsberger	Leiden University	Eindhoven	1957
A.J. (Bert) Staverman	TNO	Leiden	1958
D.W. (Dick) van Krevelen	AKU	Delft	1960
A.J. (Adriaan) Wildschut		Delft	1960
D. (Derk) Heikens	AKU	Groningen	1962
E.J.J.M. (Emile) de Roy van Zuydewijn	NYMA	Eindhoven	1963
D. (Derk) Heikens	AKU	Eindhoven	1964
J. (Jan) Schuijer	DSM	Twente	1964
G. (Ger) Challa	AKU	Groningen	1965
H.R.K.N. (Hermann) Janeschitz-Kriegl	TNO	Delft	1968
A. (Adriaan) Bantjes	DuPont	Twente	1968
C.A. (Cornelis) Smolders	AKU	Twente	1969

SOURCE: Data on year of appointment and university: E. Homburg and L. Palm (eds.), *De geschiedenis van de scheikunde in Nederland 3* (Delft 2004), Appendix 1, 293-321. Data on organisation of origin: various sources.

chemist hailing originally from NYMA, managed to ensure that the laboratory was soon filled with rollers, calenders, extruders, spinning machines and the like.[73]

Many of the professors also acted as industrial consultants. Derk Heikens, for example, worked for many years as a consultant to AKU, DSM and GE Plastics.[74] In Groningen, Professor Challa continued to work as a consultant for AKU, TNO and Philips, and also undertook a number of joint research projects with AKU, including both short-term and long-term projects.[75]

Support from industry

Between 1945 and 1970, a total of 90 postgraduate students took doctoral degrees in the field of polymer chemistry. In half of these cases, the research was either performed in an industrial laboratory or supported by the chemical industry.[76] At the time when AKU substantially intensified its research activities, for example, there was also a commensurate rise in the number of 'AKU doctorates', with a total of ten doctorates being awarded over a period of eight years.

There were two main reasons why industrial companies funded academic research: in some cases, it was because the project was based on a company's own research interests. In others, a university might approach a company with a request to support a potentially interesting field of research. In both cases, however, the companies in question did not exert any influence over the research as such. A quarter of the PhD students of Professor Challa in Groningen fell in this category.[77]

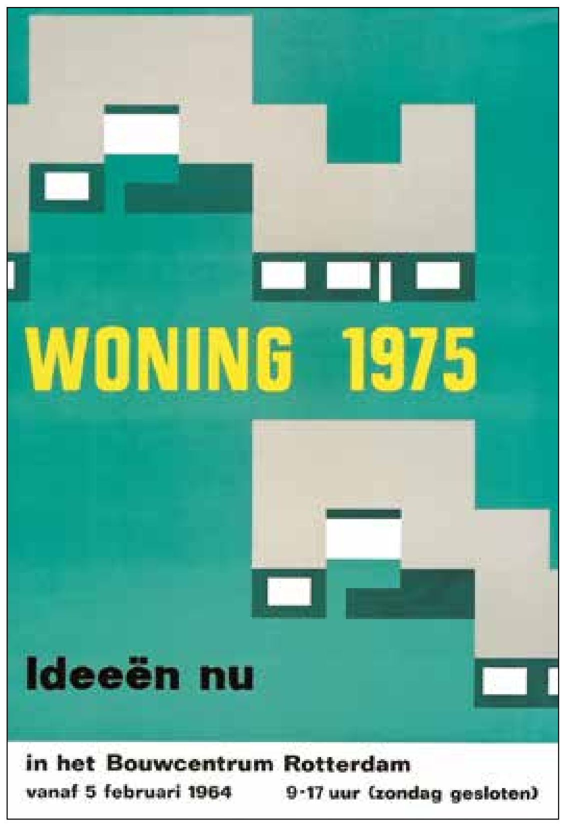
It is interesting to note that, during these early years of development, it was the chemical industry that set the lead in university research projects. For example, research into blends did not really get off the ground until AKU and General Electric had discovered that two plastics, PS (polystyrene) and PPO (polyphenylene oxide), were fully miscible, upon which Professor Challa in Groningen and Professor Heikens in Eindhoven launched research projects into blends and composites.[78]

The Netherlands as the European centre of plastics

The Netherlands could hardly be described as a plastics powerhouse after the war. After all, the Dutch produced very few plastics compared with the US and the UK, made little use of plastic products, and possessed very little knowledge of plastics. It was not until 1969 that the amount of plastic available in the Netherlands, i.e. the sum of industrial output and imports, exceeded the 'magical' threshold of one million tonnes for the first time. The fact was that the plastics industry in the Netherlands developed so rapidly in the 1960s that no other European country could match its average growth rate. No other European country exported as much plastic as the Netherlands, which exported the bulk of its plastics to other European countries. Indeed, a German trade journal described the Netherlands as 'the new European centre of plastics'.[79]
The Dutch trade journal *Plastica* rightly ascribed the success of the Dutch plastics industry to the country's favourable geographical location for the petrochemical industry, which was the plastics producing industry's main supplier of raw materials. Together with the government's active industrialisation policy, this resulted in a favourable investment climate of which both domestic and foreign companies made the best possible use. Thus, foreign companies accounted for a significant part of the industry's productive and innovative capacity.

Knowledge infrastructure

Although the industry's concentration in the Rhine delta and the post-war industrialisation policy



Poster of the 'Woning 1975' (Housing 1975) exhibition held at the Bouwcentrum in Rotterdam in 1964. The exhibition highlighted future trends in housing construction, with special attention to new materials.

Futuristic bathroom made entirely of polyester on display at the 'Woning 1975' (Housing 1975) exhibition in 1964

were both vital contributing factors, the title of 'centre of plastics' was also predicated on the presence of a thriving plastics platform. Building the core of a plastics platform was to cost an enormous amount of time and energy. Shell, DSM, AKU and TNO were the main builders. AKU already boasted a history in plastics. Shell and DSM were both newcomers who still needed to build up a niche for themselves in an open economy in which they had to compete on the world market with large, knowledgeable players.

The developments at Shell go to show that the process of building up a profitable plastics arm was no sinecure in these circumstances. The cyclical nature of the industry, combined with the fierceness of the competition, meant that Shell frequently found itself deep in the red. Indeed, Shell was only able to keep its plastics subsidiary going with the aid of the profits made by its oil company. It was not until the end of the 1960s that Shell's managers and researchers succeeded in earning a profit from the group's plastics activities. DSM and AKU both performed better in this respect.

The knowledge infrastructure formed the heart of the plastics platform. This was where the expertise was generated for making plastics, developing new plastics, improving their properties and aligning them more closely with customer needs. However, creating the infrastructure was a difficult task. The only parties capable of doing so were the big multinationals, who had access to sufficient resources of their own, and TNO, which was funded by the Dutch government. It took them at least ten years to get the infrastructure up to the desired standard. This was the work of an ambitious generation of natural scientists and engineers. Their ranks included such pioneering figures as Dick van Krevelen, Jan Hermans, Roel Houwink and Bert Staverman, together with well-known researchers such as Leo Vollbracht, Derk Heikens and Ger Challa.

If there was one factor responsible for the ultra-rapid growth of the plastics industry, however, it was the tremendous rate of growth in the demand for plastics. But where did this demand originate? Why were plastics so popular? Were there no obstacles to the growth in demand? These are just some of the questions addressed in the next chapter.

A plastic house

The fully plastic Monsanto House of the Future was one of the big attractions at Disneyland in California from 1957 to 1967. In 1968, after over two million visitors had seen the house and after it had been hit by two earthquakes, Disneyland decided that the time had come to demolish it. This was easier said than done, however. A wrecking ball weighing over a tonne simply bounced back, chainsaws broke on the tough plastic and, when it was decided to use a crane to try and prise the house loose, all that happened was that the crane became detached from its anchoring. In the end, the house was finally knocked down two weeks later with the aid of steel choker chains.

Around 50 plastic buildings of various types were erected in different locations around the world during the 1950s and 1960s. A Dutch architect, called Pijpers, designed the first plastic house in the Netherlands in 1960. The client and construction supervisor was a man called Frits Bode, one of the co-founders of the Association for Promoting the Use of Plastics in the Building & Construction Industry. The house consisted of just one storey and occupied a floor space of 70 square metres. Two years later, another Dutch company (N.V. Verkoopkantoor Passementerieën VPI) commissioned a plastic bungalow, and in 1964 Fokker, the Dutch aircraft-makers, produced what was styled as an 'instant home'.

In 1967, a consortium consisting of *Nederlandse Aardoliemaatschappij* ('the Dutch Petroleum Company', or NAM), the Royal Shell Plastics

Delegates of various women's advisory committees ('Vrouwen Adviescommissies', VACs) in the Netherlands pay a visit to the Fokker Instant Home at the Fokker site near Amsterdam Airport. The house was largely made of plastics.

Marvin Goody at the Monsanto House of the Future at Disneyland. The house was designed by MIT architecture professors Marvin Goody and Richard Hamilton, and the photograph was shot in June 1961. Goody is holding the blueprints of the building.

Laboratory and the Holland Building Corporation conducted a trial with two experimental bungalows, in partnership with Bruynzeel, Hatéma, Krommenie Linoleum and Philips Nederland, among others. The project, which was later to be known as the 'Shell Plastic House', was not 100% plastic. A steel structure supported the space grid that in turn supported the roof. Inside the house, a vapour barrier had been placed between a layer of foam and a layer of asbestos concrete in order to prevent condensation and mildew. The inner walls were built as chipboard sandwiches with a polystyrene core. Apart from that, the skirting-boards, seal sections, glazing beads, ceiling elements, rainwater pipes, sewers, inner doors, overpanels and the bathroom were made entirely of plastic. The designers claimed that the system used in the experimental bungalows was also suited for high-rise and non-residential buildings. When the Royal Shell Plastics Laboratory in Delft later moved into new premises, the move was seized as an opportunity to gain experience with the use of plastic in a multi-storey building.

The TNO Plastics Institute referred to the experiments as a chance to build 'unusual plastic castles rather than castles in the air'. However, the idea of a fully plastic house did not prove a success and was later abandoned. Nonetheless, plastic began to permeate the building & construction industry in all sorts of other ways.

SOURCE: E.M.L. Bervoets and F.C.A. Veraart with assistance from M.Th. Wilmink, 'Bezinning, ordening en afstemming 1940-1970', in: J. Schot, H. Lintsen and A. Rip, *Techniek in Nederland in de twintigste eeuw* (Zutphen 2003), Part VI, 229-233.

5. The changing image of plastics

Contemporary or contemptible?

Plastics encompass a wide range of materials and products and there was a huge rise in the number of applications around the year 1950. The fact was that plastics manufacturers in the US, the UK and Germany had vastly stepped up their production capacity during the war years so as to keep up with the demand from the armed forces. Once this market evaporated, however, plastics manufacturers found themselves 'all dressed-up with nowhere to go'.[80] Big, new markets soon began to appear, though: the construction industry, textiles, electronics, packaging and the automotive industry all wanted plastics. The consumer market also looked very promising, with consumers on the lookout not just for plastic imitations of products originally made of metal, wood or ceramics, but also for completely new products. Indeed, during the Great Depression, industrial designers in the US had already started out on a quest for new applications and attractive, new designs.[81]

One of the main advantages of plastics over other materials was that they were eminently suited to mass production. Another was their plasticity: they could be moulded into all sorts of different shapes. Moreover, thanks to all the research that had been performed, it was now possible to produce plastics with widely divergent properties. As a result, plastics began to be perceived as a magic material 'with a thousand uses'.

Scientific journals

Their public image was reflected by a series of publications in both scientific and non-specialist journals shortly after the war, in which the authors waxed lyrical about the merits of the new material. For example, a general reference work written by J.J. Moerkerk in 1947 began with a description of plastics before moving on to other inventions such as the electron microscope, DDT and penicillin.[82] Writing in *Practical plastics illustrated: A clear and comprehensive guide to the principles and practice of modern plastics* in the same year, the US chemist P.I. Smith claimed that:

> 'The combinations and permutations possible in modern synthesis are practically limitless. We are, indeed, on the fringe of great discoveries, and it needs no twentieth-century Jules Verne to tell us that the Plastics Age is just round the corner. The industrialist realizes that plastics materials are better suited to many mass-production methods of manufacture than are metal, wood and ceramics. Plastics, therefore, offer him a means of supplying large markets with goods at competitive prices. To manufacturers in many industries (...), plastics are of immediate interest because of their versatility and combination of unusual properties.'[83]

Long rows of asparagus beds covered with plastic mulch film in the spring

Similar noises were also heard in the Netherlands, where J.C. Derksen, a chemist, praised the versatility and unique properties of plastics in *Plastica: de moderne, organische synthetische materialen* ('Plastics: the modern, organic, synthetic materials'):

> 'The material does not change its appearance in most conditions, and also retains its glorious sheen. (...) For a construction material, hard plastics are light in weight and are generally mechanically strong. Their strength is the same in all directions, as opposed to wood, where the strength along the grain is completely different from that across the grain. Pliability can be varied at will. These materials are available in every shade of colour – and even in the form of a transparent mass. They are electrical insulators that, if so desired, may be produced with outstanding insulating properties. Finally, and perhaps most importantly, they are easy to shape and hence eminently suited to modern mass production.'[84]

Popular magazines

Magazines for the general public were also enthusiastic. For example, a Dutch women's magazine called *Libelle* ran an article in 1946 under the heading: 'Plastic. The wonder-product'. A Dutch weekly, *Elseviers Weekblad*, referred to plastic as 'the magic word of the modern age'. And one of the Dutch dailies, *Het Nieuws,* also referred to plastic as 'the magical materials of today'.[85] Consumers were ready to follow the fashionable idea that 'they were buying something "American".'[86]

Dutch Minister of Economic Affairs Jan de Pous at the opening of the Macro Plastic trade fair in Utrecht, 1960

Camping shower cabin on display at the HISWA Amsterdam boat show in 1960

The mood of enthusiasm immediately after the war was kindled not just by the material's special properties, but also by its image. Plastic was 'American' and represented progress. In short, plastic was the very essence of modernity.

However, there was also a risk inherent to the vast potential of plastics – of their not being used for the right purposes. As early as 1944, an American journal called *The Scientific Monthly* warned that:

> ' ... plastics are not cure-all or all-purpose materials any more than are wood, glass, leather, or steel and other metals, and they are subject to the same tests of worth ...'[87]

First image problem: poor quality

Nonetheless, plastics were put to more or less any use in both the US and the Netherlands. Their image suffered as a result after the war. As one Dutch author remarked: 'Remember the craze for plastic rain coats?... On the whole, this mass-produced article proved a huge disappointment during the first few years after the war.'[88] A number of plastic products proved to be of inferior quality to those made of traditional materials. Indeed, a researcher at the TNO Plastics Institute wrote in 1949 that 'in the eyes of many a housewife, the status of plastics was soon downgraded from that of "wonder products" to "rubbish" or "cheap junk".

And why? Either because the manufacturer had chosen to produce the article in question with the wrong kind of plastic, or (more commonly) because the housewife herself, not being adequately informed, failed to use the article in the right way.'[89] In other words, it could just as easily be the consumer's fault.

Second image problem: fire hazard

Fire risk was another problem. Certain plastics were liable to catch fire easily. The issue was a delicate one. In the 1960s, the General Association for the Use of Plastics in Construction formed a committee to draw up a set of fire safety standards. The committee was made up of nine different parties, including TNO (the Netherlands Organisation for Applied Scientific Research), members of the plastics industry, the Netherlands Association of Senior Fire Officers and various associations involved in enforcing the Nuisance Act and supervising construction work. TNO's Fire Safety Centre was given the job of developing testing methods and mounting a public information campaign. However, it remained a delicate issue, even within the committee:

> '… Mr Levinson [*representing AKU*] questioned the objectivity of the TNO Fire Safety Centre in informing senior fire officers about the behaviour of plastics in the event of fire. Mr Beek [*also representing AKU*] commented in this connection that this impression had arisen primarily as a result of the emotional approach to the issue taken by Mr Van Elteren [*a member of the Centre's staff*]. It was decided to discuss the matter with the Fire Safety Centre …'[90]

The interior of a bookstore in Amstelveen (Netherlands), 1962. Melamine-topped tables are conveniently placed, allowing customers to browse and read books.

There were also problems with the supply of plastic sheeting for testing by TNO, whose testing procedures were regarded as being questionable.

Information campaign

The TNO Plastics Institute joined forces with plastics manufacturers to mount an information campaign that was directed at the plastics processing industry and which embraced all these various issues. The idea was both to explain the potential offered by plastics and their limitations, and also to control the way in which plastics were used. After all, many of the problems resulted from plastics being wrongly used or from good-quality plastics being processed in the wrong way. Indeed, writing in a journal called *Gemengde Branche* ('Mixed Industry'), the TNO Plastics Institute claimed that 'there are no bad plastics. There are just manufacturers who use the wrong plastics as the basis for their products'.[91] The Institute did admit that the wrong (generally meaning cheap) plasticisers were sometimes used, particularly in the production of PVC, and that these had resulted in certain materials and applications being substandard.[92] In most cases, however, it was not the material that was the problem. TNO, and the Plastics Institute in particular, invited manufacturers and shopkeepers to contact them for advice on the use of plastics in consumer goods.

Marketing campaign

Alongside this public information campaign, an active marketing campaign was also launched to boost the public image of plastics.[93] And indeed, by the end of the 1950s and during the 1960s, plastics were once again enjoying a revival in their reputation as 'strong, hygienic, washable, lightweight, colourful and (…) well-designed'.[94] For example, *Consumentengids*, the main Dutch consumer magazine, had the following to say in

A supermarket in Lelystad (Netherlands), 1967

November 1958 about the growing popularity of plastic tabletops:

> 'At first, these new, practical materials were used exclusively in kitchen tables. But now, plastics are also starting to be used as tabletops in the living room. And with good reason: they are well suited to modern interior design and are amazingly easy to maintain.'[95]

Although a 1963 *Consumentengids* consumer test of plastic crockery in 1963 came up with a mixed bag of findings, the *Mosalite* plates and cups and saucers (made of melamine) were highly rated.[96]

In short, the image of plastics underwent a change in the period from 1945 to 1970, moving first from magical and modern to cheap and fragile, before switching to modern and hygienic. After 1970, the image changed further: plastics were now also associated with depletion of natural resources and environmental degradation.

Plastic milk churns being displayed at the Phoenix Packaging Fair in the Netherlands, 1961

Disposable packaging and waste

In the old days, people were thrifty, taking great care of their limited quantity of belongings. Things changed in the 1950s and 1960s, however, with the sudden profusion of consumer goods. The economy grew at an unprecedented rate, leading to a tremendous rise in wealth and prosperity. It was not only the rich who benefited: the new prosperity permeated all layers of the Dutch population. This trend was reflected by a rapid rise in consumption and new forms of purchasing behaviour. Fashion and trends began to play an important role for Dutch consumers, who were now able to choose from a large quantity of products, and had no hesitation in throwing away their recent purchases whenever new products appeared on the market.

Another characteristic feature was the rise of self-service shops and disposable packaging.[97] Both aspects formed part of the 'American dream' cherished by many Dutch housewives. The self-service shops – supermarkets – promised quick and easy shopping and were associated with prosperity, luxury and individualism. One of the preconditions for their existence, however, was that foodstuffs had to be prepackaged. The result was large quantities of packaging waste. The overriding trend was towards a consumer society, accompanied by a desire for innovation and the rise of a 'throw-away mentality'.[98] Let's now take a closer look at the issues of disposable packaging and waste in particular.

The first types of disposable packaging were made of paper, glass and tin. With their unique characteristics, however, plastics were also highly suitable packaging materials. Thanks to their light weight, low material cost and the ease with which they could be shaped, they gradually assumed a reputation as an ideal material for disposable packaging.[99] This quote from an article in *Modern Packaging* in 1957 illustrates the growing awareness of the new potential offered by plastics:

> 'The biggest thing that's ever happened in molded plastics so far as packaging is concerned is the acceptance of the idea that packages are made to be thrown away. Plastics molders are no longer thinking in terms of re-use refrigerator jars and trinket boxes made to last a lifetime. Taking a tip from the makers of cartons, cans and bottles, they have come to the realization that volume lies in low-cost, single-use expendability. (...) Consumers are learning to throw these containers in the trash as nonchalantly as they would discard a paper cup – and in that psychology lies the future of molded plastic packaging.'[100]

Interesting as it is to read that the future of plastics apparently lay in the production of single-use packaging, it is perhaps even more intriguing to see that the author was also drawn to the 'psychology' of consumption. Little is known, in fact, about the acceptance of disposable articles and packaging in the Netherlands. It is probably safe to assume that, in a country such as the Netherlands – which prizes thrift – there would have been less evidence of a 'throw-away mentality' than in countries such as the US. The key issue in the debate on packaging was not so much the principle of throwing things away and the mountain of waste that this habit would cause, as the question of the rising cost of products.
In the 1960s, for example, the leading Dutch consumer magazine regularly grumbled about the extra price consumers had to pay for the cost of disposable packaging.[101] Many newspapers also reported on price rises caused by disposable packaging.[102] Despite this, figures published in the *Compendium voor de Leefomgeving* ('Compendium for the Environment') pointed to a marked rise in the volume of household waste during the 1950s and 1960s (see Graph 5.1).[103] Indeed, the volume of household waste on a per capita basis doubled between 1950 and 1970. The share of plastics in this remained limited, however, at around 5% of the total (see Graph 5.2). Slowly but surely, the question of how to dispose of all this waste became ever more urgent.

Three methods of waste processing

Plastics play a special role in terms of waste processing. During the first half of the 20th century, there were essentially three main methods of processing waste. The first involved recycling: reuse was the traditional way of dealing with unwanted products. Used clothing gained a new lease of life on the second-hand market, and any clothes that were completely worn out were used for the production of paper. Bones were collected for use in the production of glue, and domestic refuse was combined with faeces for composting.

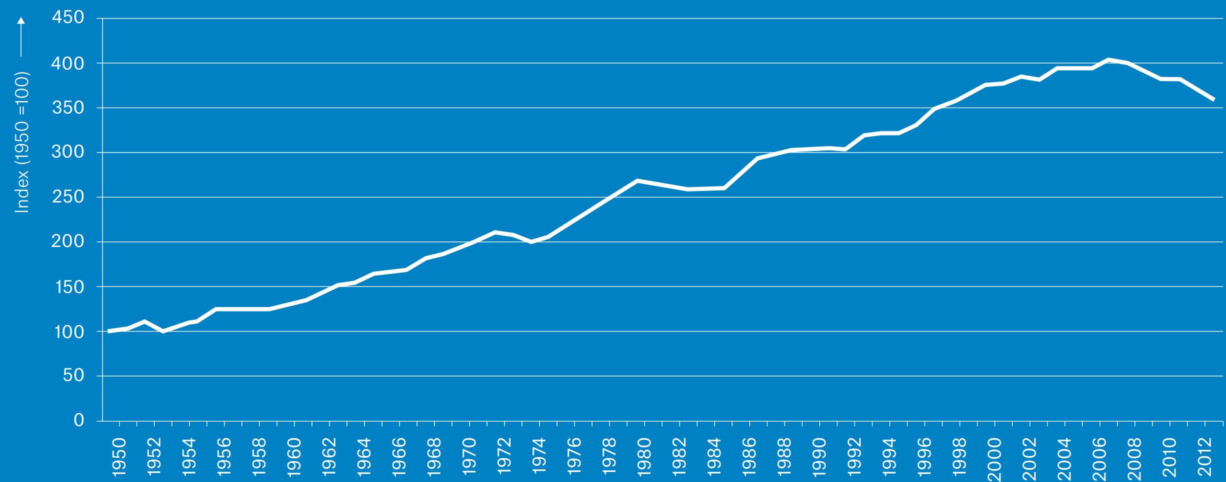
The second method was the incineration of waste, either raw or after compression into briquettes. Finally, waste was also tipped, either on rubbish dumps in or on the outskirts of towns, or in pools or marshes.[106]

However, as plastics began to account for an ever greater share of waste volumes, all three options grew more and more difficult.[107] Composting had already been complicated by the mixing of other, inorganic materials with household waste. The presence of glass and metal made the waste unsuitable for composting into fertiliser, and the problem was the same with plastic.

Incineration, for its part, had always caused nasty smells and air pollution, but the problem was exacerbated once plastics were combined with the waste. Incineration meant that the additives and plasticisers used in the production of plastics found their way into the atmosphere, where they were capable of causing damage. A government committee on waste disposal noted in 1970 that 'one way of solving the problem of toxic gases [*such as dioxin*] could be by building a tall chimney.'[108]

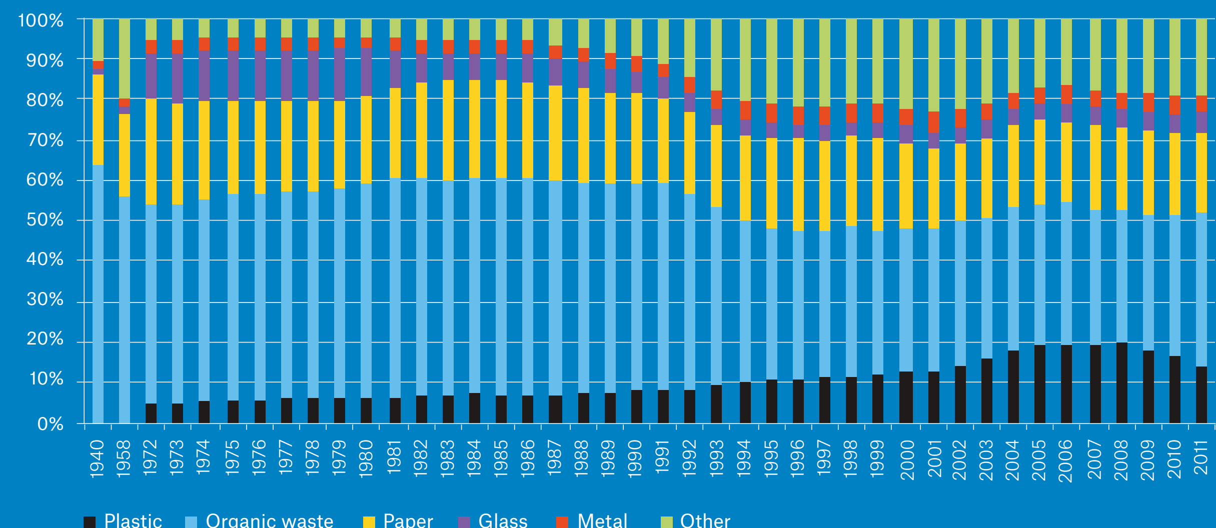
The third method, dumping, ran into difficulties on account of the growing quantity of waste that was produced. There was a risk of a shortage of suitable landfill sites. Although plastic products

GRAPH 5.1 Household waste per capita, 1950-2013 (1950=100)[104]



SOURCE: Statistics Netherlands, Netherlands Environmental Assessment Agency & Wageningen University and Research Centre (2014)
Note: The graph is based on the weight of household waste.

GRAPH 5.2 Composition of household waste by weight, 1940, 1958, 1972-2011[105]



SOURCE: Statistics Netherlands, Netherlands Environmental Assessment Agency & Wageningen University and Research Centre (2013)
Note: The graph is based on the weight of household waste.

made up only a small proportion of the waste, many of them were hollow, which meant that they took up a relatively large amount of space and undermined the stability of rubbish dumps. Also, once a rubbish dump had been covered over, plastic waste took much longer to set than conventional waste.[109]

Biodegradability?

Despite this, these objections were seldom raised in articles published in the 1950s and 1960s.[110] Another problem was, however, raised in the press, and this was the fact that plastics were not biodegradable. For example, one local newspaper reported in 1964 that the *Vuil Afvoer Maatschappij* ('Waste Disposal Company', or VAM) was fed up with the growing mountains of discarded nylon stockings at its site in the province of Drenthe: these mountains were becoming so large, VAM complained, that 'you could ski down them'.[111] The Dutch press reported on attempts being made in the UK to produce degradable plastic packaging so as to resolve the problems caused by plastic waste.[112] An American chemist wrote, however, that the very idea of producing biodegradable plastic packaging was 'the antithesis of the nature of packaging plastics, the prime asset of which is their excellent resistance to these very processes'.[113]

Right up to the early 1970s, there was very little debate in the Netherlands about the problem of what to do with plastic packaging waste. After all, plastics still accounted for only a relatively small share of the total amount of waste. No studies were performed, either in the 1960s or even in the 1970s, into the specific problem of the plastic component of household waste. In the UK (where plastics likewise accounted for only a small share of aggregate household waste – in fact, no more than 1-2% in the 1960s), on the other hand, the Society of Chemical Industry performed a study at the end of the 1960s into the nascent problem of how to dispose of plastic waste.[114]

The first stirrings of public awareness in the Netherlands began around the year 1970. On 18 April 1970, a local newspaper in the province of Limburg ran a story, based primarily on experiences abroad, with the following headline: 'Problem for compost production: plastic packaging may pose an environmental risk'. The article itself, however, focused more on the subject matter of the sub-heading, i.e. 'Ingenious inventions on display at the International Packaging Fair', singing the benefits of plastic packaging.[115]

This was clearly not at the forefront of the mind of Theo Tromp when he opened Macroplastic, the Fifth International Plastics and Rubber Fair, in 1970. Tromp was both a director of Philips and the chair of the Netherlands Society for Industry and Trade, and made the following comment in his opening speech: 'The principle of disposable packaging has (...) clearly grown out of control. This does not of course apply solely to plastic packaging. ... One of the most important problems of our time is the role played by plastic packaging as an environmental pollutant.'[116] Litter was one aspect of these problems.

Litter

Serious commentators began to take more and more interest in the problem of street litter in the late 1960s. In itself, there was nothing new about the environmental damage caused by litter. Indeed, as early as in 1916, the main Dutch motorists' association, the ANWB, mounted an anti-litter campaign. Clean-up campaigns, generally of a local nature, were held from time to time in the following years.[117] Packaging was seen as one of the main sources of litter, although, here too, plastics initially formed only a small part of the problem.[118] A study of litter conducted in the Dutch town of Amersfoort in 1978 showed that almost half of all the litter in the municipality consisted of paper. Plastic accounted for just 21.6% of the litter collected by the researchers.[119]

Waste collection container overfilled with bin bags

Threat to animal health

Plastic litter was not just an eyesore. It also posed a threat to animal health: animals could easily get entangled in plastic netting or string, or could mistake plastic objects for food. The American ecologist Barry Commoner was one of the first to highlight the issue, writing in 1971:

> 'Having been designed for their plasticity, the synthetic polymers are easily formed into almost any wanted shape or configuration. Huge numbers of chaotically varied plastic objects have been produced. Apart from the aesthetic consequences, there are serious ecological ones. As the ecosphere is increasingly cluttered with plastic objects nearly infinite in their shape and size, they will … find their ways into increasingly narrow nooks and crannies in the natural world. This situation has been poignantly symbolized by a recent photograph of a wild duck, its neck garlanded with a plastic beer can pack … Such events … can only become increasingly frequent as plastic factories continue to emit their endless stream of indestructible objects, each predestined by its triumphant escape from the limited life of natural materials, to become waste.'[120]

However, little interest was shown in the problems of plastic disposable packaging and plastic litter around 1970. It was not until the 'green wave' broke later on in the 1970s that the debate began to take shape. Insofar as it centred on the causes, it did not specifically examine the issues of technology or plastics. The director of the TNO Plastics Institute in 1972, P.J. Bakker, claimed that litter was an educational problem.[121] It was all a question of human behaviour: people tended to dispose of their rubbish without thinking.[122] However, there was another causal factor at work here.

Bin bags

With the rise of prepackaged products, packaging represented a growing proportion of the contents of rubbish bins. As a result, there was more and more chance of small, light pieces of packaging being blown away every time a rubbish bin was left out on the streets for emptying by the local refuse collectors. And even if this didn't happen, it was easy enough for lightweight packaging to be blown away when the bin was turned upside down to be emptied in a passing dustcart. Sealable bin bags proved to be the answer. Ironically, though, these were also made of plastic.

Plastic bin bags (also known as 'refuse sacks') were first introduced in Amsterdam in 1967,[123] and quickly found their way around the rest of the country. The main benefits ascribed to such bags was that they kept the rubbish bin itself clean, enabled people to dispose of more refuse and were easier to take outdoors for collection.[124] The latter aspect was also good news for the dustmen. They also had drawbacks, though, one of the main ones being that they were not suitable for the disposal of hot ashes.[125]

Initial experiences with bin bags were one hundred per cent positive: the sealable plastic bags were regarded as being more hygienic than the old-fashioned rubbish bins;[126] they were also airtight, odour-free, and did not produce any dust. Moreover, they eliminated one of the problems associated with rubbish bins – that of full rubbish bins, which meant that any refuse which would not fit would be left out next to the bin, where it could easily make a mess in the street.[127] Just a couple of weeks after bin bags had been introduced in Groningen, the head of the local sanitation department had no doubts about their benefits: 'Initial experiences with bin bags are that they help the city to look a lot cleaner. There's much less domestic refuse littering the streets'.[128]

Environmental problems

However, critics of plastic bags were soon to raise their voices, particularly in relation to their lack of biodegradability. Various attempts were made to find alternatives, including (unsuccessful) trials with cardboard refuse boxes in Groningen[129] and a lobby campaign on behalf of biodegradable bags made of flax.[130] As ever, plastics met with an ambivalent response. Whilst they formed part of the solution to the problem of waste disposal and the containment of street litter, they also lay at the core of a new problem.

Very few people had discerned the environmental impact of plastics in the 1950s and 1960s. The situation began to change in the 1970s, when plastics were condemned, and exposed to public scorn and ridicule. The reversal in public opinion was not the only change, though. The dire state of the economy forced plastics producers to stop and rethink their strategy. Mass production began to look less and less attractive, as new, higher-quality plastics appeared on the scene. There were new trends in design and processing techniques. As universities began to play a more important role, the knowledge and research infrastructure underwent fundamental changes. These – and other – developments form the subject of Part II of this book.

The first fully plastic garden chair

Up to the 1970s, most garden chairs consisted of a metal frame with wooden armrests. Various plastic components had gradually been added to the design over the years: armrests, cups under the chair legs and a plastic cord woven around the frame. In 1980, three small firms from the province of North Brabant joined forces to produce the first lightweight plastic garden chair. The three firms were ACT, which employed some 20 people and sold garden furniture and household articles; Mago, a metalworks with a workforce of around 350; and a small plastics processor called Industrial Moulding. They had a long history of producing garden chairs together.

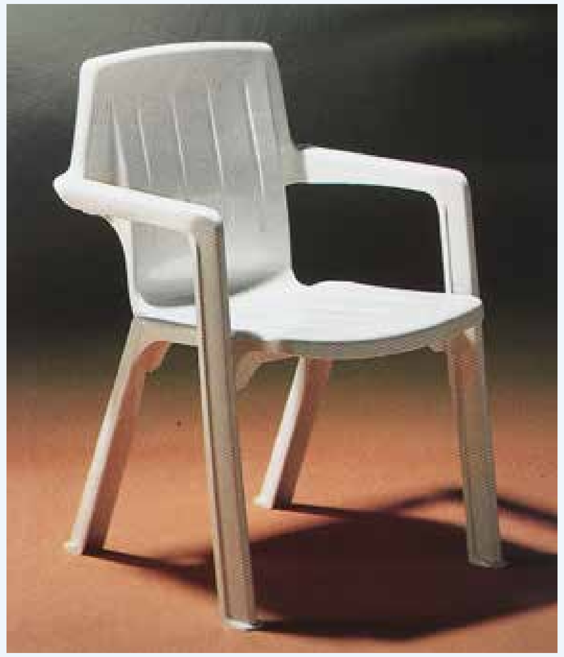
The three firms wanted to design a lightweight, folding, adjustable plastic chair for mass production. This was a different kettle of fish to a plastic ashtray, a plastic doll or a plastic radio housing. There were all sorts of technical challenges waiting to be overcome. First of all, the chair needed to be able to withstand the forces exerted by someone sitting and moving around. In other words, it needed to be resistant to pressure, shear, pull and torque forces. Nor should it buckle, break or sag badly. Another requirement was that the chair should be able to withstand the effects of weathering, and that its design should appeal to popular taste. Mago knew how to build metal chairs. ACT was familiar with the market and had an impressive network of contacts with the wholesalers who would be selling the chairs. Although Industrial Moulding had plenty of experience with processing plastics, it had acquired this mainly from simple products such as armrests. It was clear that the joint venture would need more expertise and further competences if it was to build and sell a fully plastic garden chair.

The first step was to talk to DSM as the supplier of the plastic. After all, the composition of the material was one of the main determinants of the quality and characteristics of the end product. After some debate, it was decided that polypropylene would be the best material, with a large amount of lime as a filler. The idea was for Industrial Moulding to buy new injection-moulding machines as more powerful machinery with greater pressure was now needed in order to inject the plastic and actuate the heavier moulds. Before buying the machines, however, Industrial Moulding first needed to consult machine manufacturers in the Netherlands (Stork) and in Germany (Mannesman, among others). A mould maker from Troisdorf just outside Cologne was selected to supply the moulds, as it had already made dies for car bumpers and had plenty of experience with large plastic products. TNO was asked to test the chairs.

There were still a number of outstanding problems that needed resolving when the first chairs rolled off the production line early in 1981. The main problem was with the legs, which tended to break off because they were not strong enough. The moulds were adjusted, the machines reset and the composition of the material modified. A month or so later, the problems were resolved, which meant that full-scale production of 45,000 chairs could now start – just in time for the new season. Consumers were delighted and the chairs sold out in no time. The success of the first batch of chairs signalled the start of a hectic period, not just for the three partners, but for the garden furniture industry as a whole. The explosive growth in sales of plastic garden furniture was one of the factors behind the expansion of the plastics market in general. Insiders described this period as 'the arrival of the cowboys'.

Around the year 1980, the plastics processing industry had a somewhat ambivalent image as an innovator. On the one hand, the Dutch Ministry of Economic Affairs claimed that '... the plastics processing industry had always been good at innovation.' The Ministry based this assertion on the success enjoyed by plastic as a competitor to conventional materials such as wood, glass and metal. At the same time, both the Ministry and industry representatives were constantly calling for a greater effort in training and a focus on more knowledge-intensive products and production processes. The implication was that there were two possible ways of innovating with plastics: the first was by making 'low-tech' substitute goods (a process that did not require much training) and the second involved highly qualified staff making 'high-tech' products.

The case of the lightweight, fully plastic garden chair shows that things were not as clear-cut in practice, however. Although the new garden chair was a substitute article, it was in fact high-tech in terms of the material used, as well as its design and production process. Even though the plastics platform (whose members included raw material suppliers and machine manufacturers) with its laboratories and highly qualified staff played a vital role in the innovation process, the three small firms were also immensely important actors in the story. Admittedly, none of them had its own laboratory or design department. Nevertheless, ACT, Industrial Moulding and Mago could all be described as engaging in research and development. Ideas were generated, technical drawings made, calculations done, experiments performed and prototypes produced – at home or in an office, a workshop or a production department. None of the originators had attended any form of advanced technical education. And yet they possessed crucial expertise and experience. The owner of Industrial Moulding was the son of the founder of Curver, a well-known plastic processor, and had spent some time on the latter's board of directors. Curver was bought by DSM in 1972 when it got into financial difficulties. ACT, for its part, knew a lot about consumer preferences, the design and development of garden furniture, and also about supply chain logistics and trade finance. In other words, the new product was the result of innovation with the aid of semi-skilled and highly skilled staff.



Plastic outdoor furniture, 1984

SOURCES:

Quote taken from: 'Momentopname van de kunststof-verwerkende industrie in Nederland', *Plastica* 34 (1981) no. 4, 97-100

M. Davids, H. Lintsen and A. van Rooij, *Innovatie en kennis-infrastructuur. Vele wegen naar vernieuwing* (Amsterdam 2013), 165-166, 193-195

Notes

1 A.G. Wansink, 'De Nederlandse kunststoffenindustrie in 1963 en enige toekomstaspecten', *Plastica* 17 (1964), no. 9, 452.

2 H.B. Sprietsma, 'De betekenis van de Nederlandse kunststoffenexport', *Plastica* 19 (1966), no. 12, 570.

3 The data for 1963 and 1970 can be represented in the following table:

	Estimated consumption per capita (kg/year) **1963**	Consumption per capita (kg/year) **1975**
US	18	40.4
West-Germany	20	67.1
France	10	41.6
Netherlands	10	34.4 (25)*

Source: A.G. Wansink, 'De Nederlandse kunststoffenindustrie in 1963 en enige toekomstaspecten', *Plastica* 17(1964), no. 9, 453, table IV. Estimated per capita consumption is based on the estimated domestic consumption shown in table 3.1 of this chapter.
For 1975, see 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31(1978), no. 1, 2, table 4.

The question is, however, how reliable these data for 1975 are. The domestic consumption reported for 1975 is 335 kilotonnes. The population in that year amounted to: 13,653,000. This translates to a per capita consumption of 25 kg and not 34.4. On the other hand, the latter figure is about the same as that shown in table 3.3 of this chapter. That would mean that the figure quoted in the article for domestic consumption is too low.
The following data are also available for the Netherlands:

Year	Kg/per capita
1938	0.2
1950	1
1960	9
1970	25

Source: F. van der Most, E. Homburg, P. Hooghoff and A. van Selm, 'Nieuwe synthetische producten: plastics en wasmiddelen na de Tweede Wereldoorlog', in: J.W. Schot, H.W. Lintsen, A. Rip and A.A. Albert de la Bruhèze (eds.), *Techniek in Nederland in de Twintigste Eeuw* (Zutphen 2000) Part II, 360-361.

4 R. van de Kasteele, *Het kunststoffengebied. Chemie, grondstoffen en toepassingen* (Amsterdam 1949), 29. The data for the various markets are not consistent. Van de Kasteele provided two different statistics for 1949. In one, the biggest markets were Electrical appliances (27%), Household articles (10%) and Trinkets and toys (13%). Textiles were not included. In the other set of data, the biggest market was Electrical appliances (43%), followed by Packaging (20%), Textiles (14%) and Construction materials (10%).

5 The data in table 3.6 should probably be understood as a rough indication. The figures are taken from 'Enige internationale statistische gegevens over kunststoffen', *Plastica* 31(1978), no. 1, 1, table 6. It seems no uniform standards were used for the different catagories. It is unclear, for example, under which category synthetic fibres for textiles and clothing have been included. And, likewise, whether in some countries domestic appliances come under household articles.

6 See: A. E. Schouten and A.K. van der Vegt, *Plastics. Hoofdlijnen van de huidige kennis en toepassing van de synthetische macromoleculaire materialen* (Utrecht 1966, fifth edition 1974), 240-272.

7 Ibid., 241. According to Schouten and Van der Vegt, at the beginning of the 1970s the building construction sector constituted the biggest market for plastics internationally.

8 For polypropylene, see: J. Choufoer and R. van Steenbergen, 'Polypropeen', in: H. Brüggeman, *Kunststoffen 1986. Terugblik en toekomst* (Delft 1986), 29-33.

9 'Eerste productiestatistiek van het CBS over de Nederlandse kunststofverwerkend industrie', *Plastica* 23(1970), no. 10, 528-529. The designation 'plastics processing industry' covered companies that used basic raw materials and semi-finished products to manufacture plastic semi-finished products or end-products by means of processing techniques such as extrusion, injection moulding, stamping, deep drawing, calendering and foam moulding. Companies engaged in both plastics

processing and other industrial activities provided separate data on their plastics processing activities. If a company could not provide this data, it was grouped under the heading plastics processing industry if plastics processing accounted for 50% or more of its activities. Companies that manufactured plastics-based products such as footwear, clothing, carpeting and yachts did not come under this category but were included in the categories shoe industry, carpeting industry, clothing industry, ship building, etc.

10 D.J. Bartoo, 'De proeffabriek', *Plastica* 9 (1956), 528.

11 Van der Most, Homburg, Hooghoff and Van Selm, 'Nieuwe synthetische producten: plastics en wasmiddelen na de Tweede Wereldoorlog', 364.

12 Unlike earlier plastics, which were discovered or invented by scientists such as Parkes (Parkesine), Hyatt (celluloid) and Baekeland (Bakelite). Parkes and Hyatt were the kind of inventors commonly found in the 19th century. Having had no formal education, they were self-made men whose inventions were largely the result of their own initiative. They had countless patents to their name and sought to earn money as inventors-entrepreneurs. Baekeland, on the other hand, represented the transition to a new type of inventor. While he too was an inventor-entrepeuner, he had had a university education, at Ghent University in Belgium. It was here that Baekeland conducted the first experiments that would later lead to the discovery of Bakelite.

13 A chain made up of a single type of monomer is called a polymer. A chain composed of multiple types of monomers is called a copolymer.

14 J.C. Gerritsen, 'Research in de Nederlandse industrie', *Plastica* 15(1962), no. 1, 10-11. Data on the plastics industry as a constituent of the chemical industry were not available.

15 H. Meijer, 'Kunststofverwerking', in: H. Brüggeman, *Kunststoffen 1986. Terugblik en toekomst* (Delft 1986), 134.

16 'Over plastics gesproken met de heer B.D. Alewijnse, directeur van C. Alewijnse & Co's N.V., Afdeling Nederlandsche Omnite Fabriek te Nijmegen', *Plastica* 9 (1956), 546-547.

17 J. Kohlwey, *Kunststoffen. Fabricage. Eigenschappen. Verwerking. Toepassing* (Amsterdam 1971), 124.

18 J.C. Derksen, *Plastica. De moderne organische synthetische materialen* (The Hague 1947), 81-82.

19 P. Spierings and A. Vos, *80 jaar Draka 1910-1990* (Utrecht 1990), 40.

20 *Plastica* 8 (1955).

21 *Plastica* 9 (1956).

22 'Over plastics gesproken met de heer B.D. Alewijnse, directeur van C. Alewijnse & Co's N.V., Afdeling Nederlandsche Omnite Fabriek te Nijmegen', *Plastica* 9 (1956), 546.

23 The following is based on: E.M.L. Bervoets and F.C.A. Veraart with the assistance of M.Th. Wilmink, 'Bezinning, ordening en afstemming 1940-1970', in: J. Schot, H. Lintsen and A. Rip, *Techniek in Nederland in de twintigste eeuw* (Zutphen 2003), Part VI, 222-224.

24 M. Davids, H. Lintsen and A. van Rooij, *Innovatie en kennisinfrastructuur. Vele wegen naar vernieuwing* (Amsterdam 2013), 145-149.

25 See, for example: J. van de Ven, 'Kunststoffen en het technisch onderwijs', *Plastica* 17 (1964), 2, 74-78; A. Wildschut, 'Techniek, technicus en kunststoffen', *Plastica* 17 (1964), 2, 4-14 and 'Cursus construeren in kunststoffen en rubbers', *Plastica* 22 (1969), 3, 108-109.

26 J. van Leeuwen, 'Kunststofverwerking en automatisering', *Plastica* 19 (1966), 1, 2-6.

27 See J. Deuten and R. van Est (eds.), *De kracht van platformen* (The Hague 2014). Deuten and Van Est are staff members of the Rathenau Institute. It is one of the first organisations in the Netherlands to study the topic of 'platforms'.

28 *Plastica* 5 (1952), 101. The underlining is by the authors of this book.

29 E. Homburg, A. van Selm and P. Vincken, 'Industrialisatie en industriecomplexen: de chemische industrie tussen overheid, technologie en markt', in: J.W. Schot, H.W. Lintsen, A. Rip and A.A. Albert de la Bruhèze (eds.), *Techniek in Nederland in de Twintigste Eeuw* (Zutphen 2000) Part II, 380.

30 This section is based on: A. van Rooij, The Company That Changed Itself. R&D and the Transformations of DSM (Amsterdam 2007). See also: H. Lintsen (ed.), *Research tussen vetkool en zoetstof. Zestig jaar DSM Research 1940-2000* (Zutphen 2000).

31 Van Rooij, *The company that changed itself*, 82

32 DuPont took out patents on all kinds of nylon (even the high-melting PA46, which is now a rich source of income for DSM), but the company overlooked the simplest nylon: PA6. This probably had to do with the fact that before World War II, under Carothers, something had accidentally gone wrong with the synthesis and the lab had not discovered this nylon type. Although DuPont was already earning a lot of money from its nylon patents and products, it missed a lot of money by not having this patent in its portfolio.

33 E. Homburg and A. van Rooij, 'Die Vor- und Nachteile enger Nachbarschaft. Der Transfer deutscher chemischer Technologie in die Niederlande bis 1952', in: R. Petri (ed.), *Technologietransfer aus der deutschen Chemieindustrie (1925-1960)* (Berlin 2004) 201-251, in particular 240-241.

34 T. van Helvoort and F. Veraart, 'Grondstoffen voor kunststoffen, 1945-1970', in: H. Lintsen (ed.), *Research tussen vetkool en zoetstof. Zestig jaar DSM Research 1940-2000* (Zutphen 2000), 35.

35 G. Challa, 'Polymeren', in: E. Homburg and L. Palm (eds.), *De geschiedenis van de scheikunde in Nederland 3* (Delft 2004) 231-241, in particular 232; F.M. McMillan, *The chain straighteners. Fruitful innovation: the discovery of linear and stereoregular synthetic polymers* (London 1979); H. Martin, *Polymere und Patente: Karl Ziegler, das Team 1953-1998. Zur wirtschaftlichen Verwertung akademischer Forschung* (Weinheim 2002).

36 However, for a long time to come AKU continued to believe in a bright future for rayon in the textile industry. At a conference in 1949, despite declining sales figures, an AKU salesman told a number of Dutch producers of stockings that rayon was their material of choice. He in fact stressed that rayon's potential had not yet been exhausted and that new applications would be found. See 'Verwerking van rayon en rayonvezel', *Mededelingen Vereniging van Tricot- en Kousenfabrieken* (30, 16 september 1949), 315-317. AKU stuck to this line until well into the late 1950s. See among others: Rayondag te Arnhem. *De Spindop* 1946, 2(27), 1. De Rayondag op de Jaarbeurs een grootse gebeurtenis. *De Spindop* 1954, 10(14), 1, 4-5; A. Lutgert (1956); De positie van de rayonvezel in de wereld. *Rayon Revue* 10, 209-213. This information is from Arjan van Rooij.

37 After the war IG Farben was split up into Bayer, Hoechst and BASF.

38 Davids, Lintsen and Van Rooij, *Innovatie en kennisinfrastructuur,* 128.

39 V.E. Gonsalves, 'Het physisch laboratorium', *De Spindop* 25 (25 October 1945) 4-6.

40 R. Levison, 'A.K.U. en research', *Rayon Revue* 4(1950) 4, 93-101. *AKU-HKI Textiel-Research. De textielwetenschappelijke organisatie achter de Enkalon-, Enka-, en Bredagarens* (Arnhem 1954).

41 Homburg, *Speuren op de tast*, 31-35, quote on 32.

42 P. H. Hermans, 'Ontwikkelingen op het gebied van kunstmatige vezels en van het inzicht in hun structuur', *Rayon Revue* 2 (1948) 2, 45-52. 'Cellulose onderzoek: wisselwerking tussen zuivere en toegepaste wetenschap', *De Spindop* 1953, 9 (50) 12-14.

43 G. Challa and D. Heikens, 'Bij het afscheid van Dr. Ir. P. H. Hermans', *Chemisch Weekblad* 59 (1963) 177-179.

44 G. Challa, 'Polymeren', in: Homburg & Palm, *Geschiedenis van de scheikunde*, 231.

45 Homburg, *Speuren op de tast*, 40, table 4.

46 B. M. Sweers (1958). 'Wat is nu eigenlijk de AKU?', *De Spindop* 14 (51), 16-19: 19. Klaverstijn 1986, 23-32-35.

47 'Bronswerk gaat Akulon-buizen toepassen', *De Spindop* 1956, 12(9); 'Buizen van Akulon: omwenteling in zicht', *De Spindop* 1956, 12(13), 4-5. The information is from Arjan van Rooij.

48 K.F. Mulder, *Choosing the corporate future. Technology networks and choice concerning the creation of high performance fiber technology* (PhD dissertation, Groningen University 1992), 58, 80.

49 The following is based on: K.F. Mulder, *Choosing the corporate future. Technology networks and choice concerning the creation of high performance fiber technology* (PhD dissertation, Groningen University 1992).

50 Ibid., 81.

51 Van Krevelen was appointed Head of Research and member of the Board of Directors at Akzo.

52 This section is based on: E. Homburg, A. van Selm & P. Vincken, 'Industrialisatie en industriecomplexen: de chemische industrie tussen overheid, technologie en markt', in: J.W. Schot, H.W. Lintsen, A. Rip and A.A. Albert de la Bruhèze (eds.), *Techniek in Nederland in de Twintigste Eeuw* (Zutphen 2000) Part II, 385-390. See also: S. Howarth & J. Jonker, *Stuwmotor van de koolwaterstofrevolutie, 1933-1973. Geschiedenis van Koninklijke Shell* (Amsterdam 2007), chapter 5, 331-381.

53 Homburg, Van Selm and Vincken, 'Industrialisatie en industriecomplexen', 387

54 Ibid., 388-389.

55 Howarth and Jonker, *Stuwmotor van de koolwaterstofrevolutie*, 349.

56 Ibid., 349.

57 Ibid., 359.

58 Homburg, Van Selm and Vincken, 'Industrialisatie en industriecomplexen', 389-390.

59 Hypothesis by Howarth & Jonker.

60 Quote taken from S. Howarth & J. Jonker, *Stuwmotor van de koolwaterstofrevolutie, 1933-1973. Geschiedenis van Koninklijke Shell* (Amsterdam 2007), 332.

61 Besides DSM and AKU, there were other companies that were also successful in the field of plastics. A good example is the Belgian company Solvay, a succcessful producer of products such as PVC. According to Homburg, one of the main success factors in the case of Solvay was the company's experience in many foreign markets. Moreover, Solvay also paid a lot of attention to marketing and technical-commercial support. K. Bertrams, N. Coupain, E. Homburg, *Solvay. History of a multinational family firm* (Cambridge 2015), 348-349. This probably did not apply to Shell. According to Howarth and Jonker, Shell's product range was perhaps also too broad. Shell's ambition was to work backwards 'from an end-product for which we envisage a profitable market and for the production of which we, thanks to our special know-how, are better positioned than our competitors'. The company's proprietary and cheap raw materials formed the backbone. According to Howarth and Jonker, the company's patent position and its competences should be the main criteria when it comes to making choices. It made little sense to enter into competition with specialised companies. In actual fact, Shell did not really manage to have a well thought-out policy, nor was there sufficient coordination. The result of all this was a heterogeneous assortment of products. S. Howarth & J. Jonker, *Stuwmotor van de koolwaterstofrevolutie, 1933-1973. Geschiedenis van Koninklijke Shell* (Amsterdam 2007), 361. Further study is needed to better understand why Shell's plastics activities were (economically) not such a success.

62 This section is based on: H. Lintsen et al., *Tachtig jaar TNO* (Delft 2012), 39-42

63 *Chemisch Weekblad* 41 (1945), 112.

64 R. Houwink, *Chemie und Technologie der Kunststoffe* (Leipzig 1939); R. Houwink, *Grundriss der Kunststofftechnologie* (Leipzig 1943).

65 H.A.M. Snelders, *De geschiedenis van de scheikunde in Nederland 2. De ontwikkeling van chemie en chemische technologie in de eerste helft van de twintigste eeuw* (Delft 1997), 184.

66 The history of the Plastics Institute is as follows. Since 1936, there had been a Rubber Foundation (different from the Rubber Institute). This Foundation had been set up by the Minister of Colonies of the Netherlands and the International Association of Rubber Cultivation in the Dutch East Indies, an organisation created in order to promote the use of natural rubber through research and marketing. The Foundation had its own laboratory at the Delft Technical College, next to the laboratory of the TNO Rubber Institute. During the war, the Germans informed the Rubber Foundation that its personnel was to be deployed in Germany. Research, the Germans said, was no longer necessary as natural rubber was no longer available. The Foundation pointed out that there was great need for research into plastics. The Foundation succeeded in convincing the Germans. The Rubber Foundation personnel was allowed to remain and was

assigned to the Plastics Institute. After the war, in 1946, the Plastics Institute was transferred to TNO.

67 The department was called the Testing and Analysis Department. The analytical-chemical work was concentrated in the analysis section. By the nature of its work, this section operated largely independently of the Testing section.

68 See also: Homburg, *Speuren op de tast*, passim

69 Delft Technical College (now: Delft University of Technology) can be seen as an exception. Here, in the years around World War II, academics such as Extraordinary Professor F. van Iterson and Unsalaried Professor R. Houwink were doing research in the field of polymer science. They were primarily employed elsewhere, however: Van Iterson at the Dutch State Mines and Houwink at the Rubber Foundation (and the TNO Plastics Institute).

70 Homburg, *Speuren op de tast*, 41.

71 J.Th.G. Overbeek & J.H. van der Waals, 'Levensbericht J.J. Hermans', in: *Levensberichten en herdenkingen* (Amsterdam 1998) 41-46, see page 42.

72 J.J. Hermans, *Vormeigenschappen van grote molekulen* (Oration, Groningen and Batavia 1947) 15, 17.

73 D. Heikens, personal communication 31 March and 12 April 2011.

74 Ibid., 10.

75 G. Challa, 'Veel meer polymeer', in: *Werken aan scheikunde. 24 memoires van hen die de Nederlandse Chemie deze eeuw groot hebben gemaakt* (Delft 1993) 465-482, see pages 468, 481.

76 The main source consulted to track polymer chemistry dissertations originating in the Netherlands in the period 1946-1979 was: *Catalogus van academische geschriften in Nederland verschenen* (Bibliotheek der Rijksuniversiteit Utrecht, 1952-1979). For all dissertations, the forewords, acknowledgements and introductions were examined to see if any information was to be found regarding industry involvement in the research.

77 G. Challa, personal communication, 16 September 2011.

78 M.J. Hollestelle (forthcoming), 'Academic Plastic? The Development of Dutch Polymer Science, 1945-1970', in: H. Zuidervaart, I. Nieuwland, E. Jorink (eds.), *Locations of Knowledge*

79 H.B. Sprietsma, 'De Nederlandse kunststoffenindustrie in 1969', *Plastica* 23 (1970), no. 5, 205

80 M. Kaufman, *The first century of plastics: Celluloid and its sequel* (London 1963), 88.

81 J.L. Meikle, 'Plastic, material of a thousand uses', in J. J. Corn (ed.), *Imagining tomorrow: History, technology, and the American future* (Cambridge 1986), 77-96.

82 J.J. Moerkerk, *Nieuwe triomfen der techniek* (Rotterdam 1947). Penicillin had of course been discovered by Alexander Fleming already in 1928, but it was not until the war that it was produced on a large scale.

83 P.I. Smith, 'Introduction to plastics', in P. I. Smith (ed.), *Practical plastics illustrated: A clear and comprehensive guide to the principles and practice of modern plastics* (London 1947), 10.

84 Derksen, *Plastica*, 95.

85 'Doorzichtig als glas, hard als staal: Plastics, de wonderstoffen van onzen tijd', *Het Nieuws. Algemeen Dagblad* 21 December 1946; note that the title speaks of *plasticS*, in the plural. As the majority of Dutch publications from this period show, the common practice was to indiscriminately refer to a variety of different plastic materials by the singular form *plastic*, as though they were all a single homogeneous product.

86 A typical example of the positive associations evoked by American plastic products is to be found in the August 1946 issue of the Dutch daily *De Tijd*, in which the prosperity/poverty of the Netherlands is compared with that of Norway. The author remarks, with a touch of envy, that in Norway it would be 'difficult to find a shop window that does not display at least something made of plastic, the new American product that is sold unrationed'. (A. Bgl., 'Zijn wij armer dan de Noren?' *De Tijd*, 1946, 3). On 19 June 1947 Dutch newspapers reported that certain clothes made of synthetic materials were to be sold unrationed. Van der Most, Homburg, Hooghoff and Van Selm, 'Nieuwe synthetische producten: plastics and wasmiddelen na de Tweede Wereldoorlog', 358-375.

87 L.H. Woodman, 'Miracles?...Maybe', *The Scientific Monthly*, 58(6) (1944), 424. The passage is quoted verbatim from the English original. J. Rinse, reporting in *Chemisch Weekblad* on the *National Plastics Exposition* held in Chicago in 1947, wrote in a similar vein: 'Increasingly, the application areas for plastomers are being defined more narrowly so as to prevent the inefficient use of these materials. It is obvious that different applications require materials with different properties, which cannot possibly be found in a single material.' J. Rinse, 'National plastics exposition te Chicago 6-10 Mei 1947', *Chemisch Weekblad*, 43 (25) (1947), 393–394.

88 'Wat maken we in Nederland? XVIII Wat maken we ervan en hoe denkt "consument" erover?', *Plastica*, 1949 (3), 342–345. It must be noted, though, that already then – in 1949 – the author remarked that the most serious problems had been solved. 'Het aantal klachten over plastic-artikelen is sterk verminderd.' ('There has been a sharp decrease in complaints about plastic products.')

89 M. Müller, 'Een praatje over plastics', *Gemengde Branche* 5 (1949), 138.

90 Algemene Vereniging Toepassing Kunststoffen Bouwwezen (The General Association for the Use of Plastics in Construction), Archival document 494, minutes of the board meeting, 28 September 1964. Quoted in: E.M.L. Bervoets & F.C.A. Veraart, 'Bezinning, ordening en afstemming 1940-1970', in: J.W. Schot, H.W. Lintsen, A. Rip and A.A. Albert de la Bruhèze (eds.), *Techniek in Nederland in de Twintigste Eeuw* (Zutphen 2003) Part VI, 236.

91 M. Müller, 'Een praatje over plastics', 138.

92 TNO's Fire Safety Centre tested the combustibility of plastics, see Lintsen et al., *Tachtig jaar TNO*, 41.

93 Van der Most, Homburg, Hooghoff and Van Selm, 'Nieuwe synthetische producten: plastics en wasmiddelen na de Tweede Wereldoorlog', 358-375.

94 G. Staal, 'Het wonder, het wantrouwen en de weerstand', in M. Boot, A. Von Graevenitz, H. Overduin and G. Staal (eds.), *De eerste plastic eeuw: Kunststoffen in het dagelijks leven* (The Hague 1981), 22. In its review of synthetic fibres in the January 1957 issue, the Dutch Consumer Magazine (*Consumentengids*) noted that all commonly used synthetic fibres performed better than cotton in almost every respect ('Synthetische vezels,' *Consumentengids* 1957); the magazine also posited that 'many consumers will probably enjoy (...) wearing a 'nylon' fur coat', although in terms of quality it could not possibly measure up to a real fur coat (''Nylon'-bont,' *Consumentengids* 1957).

95 'Het plastic tafelblad: Een onderzoek naar de eigenschappen van verschillende materialen,' *Consumentengids* 1958. Although the test results reported were largely favourable, the magazine advised readers to choose a plastic tray that would meet their specific household requirements.

96 'Plastic serviesgoed', *Consumentengids* 1963, 143–148.

97 B. Sluyter, *Kijken is grijpen. Zelfbedieningswinkels, technische dynamiek en boodschappen doen in Nederland na 1945* (PhD dissertation, Eindhoven 2007), 61-64.

98 J. Schot and D. van Lente, 'Technology, industrialization, and the contested modernization of the Netherlands', in J. Schot, H. Lintsen and A. Rip (Eds.), *Technology and the making of the Netherlands: The age of contested modernization, 1890-1970* (Zutphen, Cambridge Massachusetts 2010), 485-541. J.B. Terpstra, R. Hotchkis and W.C.M. Scheffer, *Bestrijding van zwerfvuil: Achtergronden en uitgangspunten; verslag van een voorstudie* (Nijmegen 1979).

99 G. Hawkins, 'Made to be wasted: PET and topologies of disposability', in: J. Gabrys, G. Hawkins and M. Michael (Eds.), *Accumulation: The material politics of plastic* (Abbingdon 2013), 49-67. J.L. Meikle, 'Materia Nova: Plastics and Design in the U.S., 1925-1935', in: S. Mossman and T. Morris (eds.), *The development of plastics* (Cambridge 1994).

100 Anonymous author, quoted in: Hawkins, 'Made to be wasted', 5. The passage is quoted verbatim from the English original.

101 Here are just a few examples of the protestations: 'Nieuwe verpakkingen - nieuwe prijzen: De melk-in-karton duurder,' *Consumentengids* 1966, 58; 'We gaan nog meer wegwerpen,' *Consumentengids*, 1965, 19; 'Wegwerpverpakking: Vaak heel wat duurder!,' *Consumentengids* 1964, november, 288–291. The matter of extra costs related to packaging had also featured earlier in the *Consumentengids*, in the 1950s, though at that time it was not so much about *disposable* packaging as about the extra cost of single-person (or small) packagings of products such as sprinkles. ('Verpakking gewenst?,' *Consumentengids*, 1953, september, 3)

of geneesmiddelen ('Verpakking als winstobject?,' *Consumentengids*, 1958, 23–24, 'Verpakking kan duur zijn,' *Consumentengids*, 1956, 41).

102 F. Baruch, 'Weggooien maar', *De Waarheid*, 3 December 1963, 2. In an article in the communist daily *De Waarheid*, Baruch presented data showing that the packaging for salt, for example, cost ten times more than the contents of the packaging and that the average American family spent 1500 dollars a year on packaging materials. In an article in 1964, based on a number of comparative studies, the Dutch newspaper *Nieuwsblad van het Noorden* pointed out that disposable packagings often resulted in higher prices ('Weggooi-verpakking verhoogt vaak prijs,' 1964).

103 The downward trend starting in 2008 is striking. According to the Compendium, the volume of waste probably has to do with economic developments and that the decline during 2008-2013 is partly explained by the economic crisis in this period. R.G. Stokes, R. Köster and S.C. Sambrook, *The business of waste: Great Britain and Germany, 1945 to the present* (New York 2013). Stokes, Köster and Sambrook also emphasise that the 'waste flood' to be seen in West Germany and the UK from the mid-1950s is the result of economic developments.

104 The data for 2012 and 2013 are based on tentative figures. Graphs 5.1 and 5.2 are presumably based on weights. This is not clear from the Compendium data on the website, but one of the sources referred to for the technical data is Statline electronic databank of Statistics Netherlands, which gives quantities in weight.

105 Association of Dutch Municipalities. V*uilverwerking: Rapport van een commissie, ingesteld door het bestuur van de Vereniging van Nederlandse Gemeenten* (n.p. 1964); T. Vries, 'De geschiedenis van plastic', in: M. Boot, A. Von Graevenitz, H. Overduin and G. Staal (eds.), *De eerste plastic eeuw: Kunststoffen in het dagelijks leven* (The Hague, 1981), 10-18. According to Vries, plastics accounted for 1% of household waste in 1960. It is worth noting that based on these figures, there would seem to have been no plastics waste back in 1940 and 1958. This does not seem very likely at least for 1958, but the fraction must have been so small that it was hardly worth reporting. The composition of waste in Rotterdam in 1958 also does not single out plastics; wood, straw, leather and rubber are bundled into a single category, but even this represents only about 2% of the total waste volume.

106 H. van Zon, *Een zeer onfrisse geschiedenis: Studies over niet-industriële verontreiniging in Nederland, 1850-1920* (The Hague, 1972). Van Zon rightly points out that although such areas are now defined as nature reserves, in the 19th century they were seen as wasteland. However, waste from some of the dumps that were in use in Groningen in 1970 was still being disposed of in pools and marshes.

107 P.J. Bakker, director of the TNO Plastics and Rubber Institute, denied in 1972 that there were any problems with the dumping and composting of waste: '...household waste with a plastics content of only about 3 percent present hardly any processing problems'. (P.J. Bakker in 'TNO: kunststoffen sparen milieu,' 1972, p. 11).

108 Waste Management Committee, *Vuilverwijdering in de provincie Groningen* (Groningen 1970), 11.

109 J.J.P. Staudinger, *Disposal of plastics waste and litter* (Londen 1970).

110 In 1974 a local newspaper in the Frisian city of Leeuwarden cited a study into the composition of a several-years-old waste tip. According to this study, there were no extraordinary waste processing problems specifically related to plastics. Plastic bottles (as opposed to glass) did appear to have been pressed into place and had moreover weathered ('Wetenschap: Kunststoffen,' 1974). In the 1970s, various reports were published on the subject of waste processing and the likely problems concerning the availability of suitable landfill sites (see, for example, the report *Vuilverwijdering in de provincie Groningen* by the Waste Disposal Committee); in these reports, plastics were hardly ever explicitly named as problem materials.

111 'Wegwerp-verpakking komt er steeds meer in', *De Tijd-Maasbode*, 30 April 1964, 6. This passage is to be found on the page with the heading *De vrouw en haar tijd* (The Woman and Her Epoch) and is somewhat feminist in tone.

112 'Persschouw: Plastic', *Nederlands Dagblad* 27 July 1970, 2. See also: Stokes, Köster and Sambrook, *The business of waste: Great Britain and Germany*.

113 Staudinger, *Disposal of plastics waste and litter*, 83. Quoted verbatim from the English original.

114 Staudinger, *Disposal of plastics waste and litter*.

115 'Probleem voor compost-produktie: Plasticverpakking kan leefmilieu bedreigen: Nieuwe vernuftigheden op de Int. Verpakking Beurs', *Limburgs Dagblad* 1970, April 18, 9.

116 'Vijfde Macroplastic in Utrecht geopend: Wegwerpverpakking is uit de hand gelopen.' *Limburgs Dagblad*, 31 October 1970, 9.

117 Terpstra, Hotchkis and Scheffer, *Bestrijding van zwerfvuil*.

118 See also: K. Brandsma, 'Foliefabrikant: Er moet een huisvuilwet komen: "Dwing mensen afval in vuilnisbakken te gooien."' *Nieuwsblad van Het Noorden*, 31 January 1973, 15.

119 Terpstra, Hotchkis and Scheffer, *Bestrijding van zwerfvuil*. A. von Graevenitz, 'De wegwerpcultuur: een vervangcultuur', in: M. Boot, A. Von Graevenitz, H. Overduin and G. Staal (eds.), *De eerste plastic eeuw: Kunststoffen in het dagelijks leven* (The Hague, 1981), 32. According to Von Graevenitz, 'approx. 75% of all plastic waste was thrown away simply anywhere'; no evidence is provided for this claim, however, and three-quarters of the overall waste volume would represent a rather huge proportion.

120 B. Commoner, *The closing circle: nature, man & technology* (New York 1972), 162–163; G. Staal, 'Het wonder, het wantrouwen en de weerstand', in: M. Boot, A. Von Graevenitz, H. Overduin, and G. Staal (eds.), *De eerste plastic eeuw: Kunststoffen in het dagelijks leven* (The Hague 1981), pp. 19-23. Surprisingly, this has received little attention in the literature. Although Commoner does note the risk to animals, Staal in his (short) overview pays no attention to the problem of litter and animal well-being. The passage is quoted verbatim from the English original.

121 In 'TNO: kunststoffen sparen milieu,' 1972; Bakker also dismissed other examples of negative impact on the environment, such as the claim that plastics contributed to the depletion of natural resources; however, he did acknowledge the problem associated with PVC incineration. The TNO Plastics Institute had meanwhile been renamed the TNO Plastics and Rubber Institute.

122 See also: '"Zwerfvuil" opvoedkundig probleem: Plastic doet weinig kwaad in milieu.' *Leeuwarder Courant,* 1972, 17 November, 14.

123 Puttershoek, a small municipality in the western Netherlands, had successfully introduced paper bin bags already in 1965 ('Puttershoek: Van vuilnisbak tot vuilniszak,' 1 October 1965).

124 In reaction to an article published earlier, (elderly) subscribers to the *Consumentengids* drew the editors' attention to the fact that thanks to plastic bin bags it was no longer necessary to lug heavy bins around; in response to which the *Consumentengids* emphasised that the bin bags should be of a sufficiently good quality so that they did not tear. Therefore, when the bin bags were subsequently introduced in Amsterdam (and elsewhere), it was made mandatory to use only the special bags approved by the municipal sanitary department. ('De plastic zak als vuilnisbak,' 1967).

125 'Plastic huisvuilzak doet intrede in Amsterdam,' *Nieuwsblad van het Noorden* 1 December 1967, 196).

126 S. Overhof, 'Plastic huisvuilzakken verminderen geluidshinder', *Limburgs Dagblad* 30 October 1971, 39.

127 B. Loffeld, 'Vuilophaaldienst: Service die vaak te vanzelfsprekend is', *Limburgs Dagblad* 8 May 1970, 2.

128 'Groningen dringt de vervuiling terug,' *Nieuwsblad van Het Noorden* 15 November 1971, 13. Unfortunately, the article does not make it very clear whether this was the result of improved and more hygienic packaging of waste using the plastic bin bags or whether it had to do with the additional manpower that had become available for cleaning the streets because the waste collection service had become more efficient since the introduction of the plastic bin bags.

129 'Reinigingsdirecteur ziet geen heil in: Invoering milieudoos zou Groningen f4 miljoen kosten,' *Nieuwsblad van Het Noorden* 22 February 1973. p. 17.

130 *Alle Hens. Nota Vlaszak: Redelijk alternatief voor de (ónverteerbare) plastic huisvuilzak* (Laren 1977).