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On tot he second plastics revolution. What can we learn form the first revolution?
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First of all, Dutch Polymer Institute my congratulations on your anniversary. And I also would like to congratulate you Jacques and your team with the 20 years jubilee. You have a period of extensive and beautiful research behind you. A period of intensive collaboration between researchers, universities and industry. But also a turbulent period of uncertainties. At this time DPI is busy designing a new future. You are in charge of co-creating that future. I would also like to contribute to reflecting on the future of DPI
For this purpose, I will focus on the history of plastics and its challenges, and I will indicate what we can learn from history for the challenges of plastics today and thus of DPI.
As a basis for my presentation, I use the book that Jacques mentioned and that I wrote with Marijn Hollestelle and Rick Hölsgens, *The Plastics Revolution. How the Netherlands became a global player in plastics* (Eindhoven 2017, open access).

The history of plastic after the Second World War reads like a big succes story. No other material has succeeded in conquering the world in such a short period of time.
We will start with the Belg Baekeland and his invention of Bakelite in 1907. In the Netherlands was Philips one of the first firms, who applied Bakelite at his Philite plants for radio casings. Then there are three vital basic plastics: PVC in 1912, polyethylene in 1933 and nylon in 1935.
The production of plastics in the nineteenth-sixties surpassed that of wood, glass, zinc and copper. These conventional materials had taken centuries to become commonplace materials. Plastic, on the other hand, took just a few decades to complete the same journey. Ever since the nineteen-thirties right up to the present day, the rise in the production and consumption of plastics has been spectacular. The volume of plastics produced in the first decade of the twenty-first century was the same as in the entire preceding century.

Where does this success story come from? What are the pros?

The general impression of the history of plastics is that there is
no other material that is as adaptable as plastic:
no other material is capable of assuming so many different shapes,
of possessing so many different properties and
of serving so many different purposes – AND is at the same time so cheap.
Plastics are used in toys, medicine, constructions, cars, in beautiful buildings like here in the Stedelijk Museum in Amsterdam and in many other fields. In short, the sky is the limit.
No material has made life for the masses so easy, comfortable, safe and pleasant as plastic has. Plastic is everywhere and forms part of every human life. Plastic follows us from the cradle to the grave. Plastic has penetrated just about every single human culture in the world and every single economic system, regardless of the political regime. It is no exaggeration to describe the era in which we are now living as 'the plastic age'.

But plastic is also a disputed material. What are the cons?

At the same time - and precisely because of its success - the history of plastic is also riddled with very negative images, even up to the present day. The response to the large scale on which it is produced, coupled with its high degree of penetration into human society, has been ambivalent.
The question is: what is the impact of plastic on our health and how do they interact with ecosystems?
We are annoyed with plastic bags, plastic bottles and the countless other forms of plastic litter we come across on beaches, in forests and on the streets. And yet the aesthetic problem is small compared with the direct damage caused by such litter. Big pieces of plastic can be found floating on the surface of the sea and end up in plastic soup. Large numbers of turtles, albatrosses and other marine animals in Hawaii are dying as a result of all the plastic litter. The same phenomenon is also seen closer to home – along the Dutch coastline, where birds, seals and other animals are dying as a result of eating plastic waste.
Two more chapters of the same story are the issue of the depletion of natural resources and the problems surrounding CO2 emissions and global warming – although plastic does not make the most important contribution.

But there is more. Large tracts of the sea bed are covered in a layer of plastic. Extremely small particles of plastic find their way into the atmosphere, the soil, rivers and the polar ice cap.
But do they damage the environment in this way? These plastic particles absorb dioxin and other substances that are toxic. Given that they end up in the food chain, the question is: how and at what point do they pose a risk for human health and for the well-being of other species?
The modern human body contains tiny but measurable quantities of plastic. Each one of us is 'just a little plastic', as the *Washington Post* wrote and Heather Leslie - a researcher of microplastics - concludes that microplastics can damage cells and tissues and can lead to inflammation in the human body.
There is a big chance that microplastics will be one of the biggest sustainability issues in the coming decades.

Our attachment to plastic is a sort of love-hate relationship. We are aware of the disadvantages, but we can't live without the stuff. So how are we going to get out of this addictive love affair? Abolishing plastics is absolutely not the option. A modern world without plastics is not possible, but we will have to deal with plastics in a completely different way. That requires a major transition. My view is that the challenges are so great that we need a second plastics revolution.

That is an interesting issue because I speak about the second plastics revolution. So there was a first plastics revolution.
We have had a transition in plastics in the past, namely between 1945 and 1970. Can we learn from this first revolution? Let me take The Netherlands as an example to answer this question.

After the Second World War, the United States, United Kingdom and Germany were the leaders in the field of plastics. They were at the forefront of the production and use of plastics. They were also the leaders in research and development.
In contrast 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. The Netherlands had a very modest plastics producing and processing industry. The use of plastics was far behind that of the pioneers. The Netherlands also had a modest research infrastructure in plastics.

However within twentyfive years The Netherlands was worldwide at the front of the plastics sector. Plastics were the fastest growing industrial sector in the Netherlands after the Second World War, posting some amazing growth rates in the sixties, as you can see on this graph.

The Netherlands was by the mid sixties a big plastics exporter. In terms of kilos per capita, the country had become the world's leading exporter. In absolute terms, the Netherlands, together with West Germany, Japan and the US belonged in the mid seventies to the four biggest plastics exporters in the world, see this table. Furthermore, the Dutch were also big importers of plastics.
Apart from exporting plastics, the Dutch were also consumers of plastics. Domestic consumption rose from about 2 kg per capita in 1950 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 fifties.

That the Netherlands managed to build up a strong position for itself in the international plastics industry came as something of a surprise. Within a period of about 25 years the Netherlands were up there among the world's leading plastics producers. Indeed, a German trade journal described the Netherlands as 'the new European centre of plastics'

So here we have the First Plastics Revolution in The Netherlands or in other words the transition into a plastic society. What are the characteristics of that revolution?

In the first place: building up a sector for producing and processing plastics. That was not an easy job. For example, building the phenol plant of DSM in 1952. Phenol was necessary for producing the basic monomer caprolactam. DSM invest a lot in the phenol plant. But after three years – due to production problems – DSM decided to close down the plant and to buy phenol instead.
Besides a plastic producing sector, the Netherlands also build up a plastic processing sector.

Secondly: building up a knowledge infrastructure.
Here we have a remarkable aspect. The universities were not relevant in this period. Very little academic research was performed into plastics at the time. It was the laboratories of the

big industrial companies, who did research and development in polymers. The department played an important role in the introduction of new polymers.
There was also a very important public research institute in polymers and that was the Plastics Institute of TNO (TNO was the biggest public Organisation for Applied Research in the Netherlands). It was well known as KRITNO (Het Kunststoffen en Rubber Instituut TNO). I'll be back at this institute.

Thirdly: a transition is more than production and knowledge. It is also about consumption, use and creating markets. There was a large market for mass products, for example in the household. Many plastic products were cheap imitations of products of wood, glass and iron. However, many experiments in niches also had to be done. And a lot of designs were not successful, for example the futuristic bathrooms made entirely of polyester. Or for example the so-called 'instant house' largely made of plastics, built by the Dutch company Fokker.

But the First Plastics Revolution transition was more than production and consumption. It was also about image, acceptation, standards, safety and much more. Let me give a few examples: Plastics had also a bad image in the decade after the war. A number of plastic products proved to be of inferior quality to those made of traditional materials. Indeed, a researcher 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 because the housewife herself, not being adequately informed, failed to use the article in the right way.' So there were problems on the production and consumer side. And those problems were solved in the 1950s and 1960s.
Fire risk was another problem. Certain plastics were liable to catch fire easily. In the 1960s, a committee was formed to draw up a set of fire safety standards and mounting a public information campaign.
Serious commentators began to take more and more interest in the problem of street litter in the late 1960s. Packaging was seen as one of the main sources of litter, although, here too, plastics initially formed only a small part of the problem. A study of litter conducted in the Dutch town of Amersfoort showed that 22% of all the litter consisted of plastic. There were also problems with small, light pieces of packaging being blown away. Another problem was the fact that plastics were not biodegradable.

If we speak about the First Plastics Revolution or about the transition to a Plastics Society, then we speak about:

- Building up a sector for producing and processing plastics
- Creating a market for plastics products
- Building up a knowledge infrastructure
- Developing a policy and legislation to stimulate innovation, quality standards, healthy use, safety use, litter prevention and so on
- Creating a culture so that society accepts and adopts plastics

The question now is: What were the conditions for the First Plastics Revolution or what were the most important factors of the transition to a Plastics Society?

- First of all: the context is important. For example, the availability of raw materials for the production of plastics was a significant factor in the Netherlands. DSM was located above the coalfields in the south of the country. Shell had access to both oil and oil refineries. Europoort near Rotterdam was to grow into the biggest oil storage and transshipment site in Western Europe. The combination of these factors attracted foreign companies to the Netherlands.

  Another context factor of significance is urgency. A transition needs a sense of urgency. The Netherlands was rebuilding the society after the war. Industrialization was one of the most important social goals. Government and industry considered the plastics sector as one of the most important sectors to help reach that goal.
- Second: Research in labs and Development in niches. The Netherlands had to invest a huge effort in polymer science and polymer technology because it had a big backlog. And it had to create niches for all kind of prototypes of plastics and plastic products. In those niches it could develop products in a protected environment, explore the market, build networks with users. The multinationals such as Shell, DSM and AkzoNobel were the most important actors in that field. Besides, there was a very important public research organisation: the Plastics Institute of TNO (the Netherlands Organisation for Applied Research).

  How risky this field is, appears from a quote of a manager of a laboratory: 'Plastics research is a lottery with very few 'yes's and loads of 'no's.' His rule of thumb was that, out of every 100 ideas or prototypes generated by research, 20 would qualify for further development in niches and just one would culminate in commercialisation.

- Third important factor of the transition: you need a platform of producers, users, researchers and developers. After the war the plastics sector in the Netherlands rapidly evolved 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 TNO Plastics Institute.

- Finally, you need dominant 'owners' of certain problems in the transition to a plastic society. TNO Plastics took the role of the 'owner' of the plastics revolution. The researchers created networks between industry, government and social organisations. They took the initiative for the establishment of the *Journal of Polymer Science* and the technical journal *Plastica*. TNO Plastics did a lot of R&D for the industry. The institute had a very important testing department. 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. 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 Plastics was very important in the success of the first plastics revolution in the Netherlands between 1945 and 1970

What can we learn from this history?

We started with a love-hate story of plastics. We are aware of the downside, but can't live without the stuff. Plastics are expected to grow from worldwide 350 million tons per year to one billion tons per year. At the same time the problems will be huge: depletion of fossil raw materials, CO2, climate change, litter in nature, plastic soup in the sea, micro plastics.
So how are we going to get out of this addictive love affair?

What we need is a second plastics revolution.

And the essence of the second plastics revolution is the transition from a linear plastics society to a circular plastics society. We have to close the loop of the plastics value chains with renewable energy, especially those of fossil based plastics. My opinion is that fossil raw materials will continue to dominate in producing plastics for the time being and closing the loop of fossil-based plastics with renewable energy offers the best scenario for a circular plastics society in the coming decades, but there is a lot of work to do.

Take the Netherlands as an example: Of all plastics waste 7% lands into the garbage bin, the forest, the river or the sea. That percentage has to be reduced to zero. 33% is re-used and 60% is burned. Indeed, burning is at this moment the cheapest method. And indeed burning plastics is also efficiënt because we use plastics twice, namely - first - in products and – second - after use as fuel. But from the perspective of a circular chain burning is totally wrong, because the material disappears.
33% of the waste is re-used. But what kind of re-use? It is mainly down-cycling. The functionality of re-used plastics is much less than the original plastics. In a circular chain the purpose is not downcycling but recycling - producing plastics with the same functionality - and upcycling –producing plastics with a better functionality.
At this moment there is a debate in the Netherlands about stopping or reducing the collection of plastics, because there is no destination for the collected waste and the downcycled plastics. From the perspective of a circular economy, it is a wrong debate. The debate should be about reorganizing the chains, developing new separation methods, discovering new plastics that are easy to upcycle: in short doing a lot of R & D

If you talk about the Second Plastics Revolution, then you talk about a long term transition from now to 2050.
What are the conditions for the Second Plastics Revolution or what are the most important factors of the transition to a Plastics Society?

- First of all – as we have seen in history - the context is important. And again the Netherlands is in a good position with Rotterdam as the main harbour of Europe. Indeed, in a circular economy plastics litter is no longer waste , but a raw material. And the Netherlands can import it from all over the world.
  Another important factor is ‘urgency’. But there we have another problem, because at this moment there is a major urgency about climate change and renewable energy, but

much less about plastic soup, micro plastics and so on. The Second Plastics Revolution needs a greater sense of urgency.

- Second – as we have seen – a transition requires a lot of R&D: Research in labs and Development in niches: new bio- and fossil-based plastics, new methods of mechanical and chemical recycling, smart product sensing, new membrane technologies, new catalysts and so on
- The third important factor of the transition: you need a platform of producers, users, researchers, developers and government. Creating a closed plastic loop as part of a circular economy is more than simply a technical problem. Plastic products are designed primarily with the use-phase in mind. How can manufacturers and designers be encouraged to design products for the stage after use, which means the reuse stage, and solve the problem of leakage? The latter means re-engineering plastic life cycles so that sustainability is a vital prerequisite. This requires new business models and new financing models.

  Furthermore, does a closed loop not require a different type of consumer behaviour, a different way of dealing with plastics? The modern pattern is one of creative consumption: consumers constantly exchange one product for another, discarding one as they buy another. So is there a way of working the principle of creative consumption into a closed loop? What sort of culture change is needed in order to bring this about?

  Governments have a crucial role to play in this scenario. They have to break down the barriers that stand in the way of a modern, circular economy. How can they encourage manufacturers to innovate, traders to distribute products in a sustainable manner, and consumers to change their behaviour?

  You need a platform to manage all these processes, but the large number of stakeholders involved in the transition is a big problem. They include manufacturers, processors, researchers, consumers, waste processors and government bodies to list just the principal categories.
- Finally, you need dominant ‘owners’ of certain problems in the transition to a circular plastic society. The difficulty of creating a platform and designating an owner is neatly illustrated by the process of finding a solution to the problem of small PET bottles, one of the main forms of litter in the Netherlands. A partnership with the most directly concerned organisations failed to get off the ground. Even though each of the

organisations claimed to pursue a policy of ‘good corporate citizenship’, not one of them was prepared to take the lead.

- It is in this context that I have a wish for this symposium and for DPI. As I told you: the Second Plastics Revolution needs a lot of research. We have seen that TNO Plastics as research institute have played a very important role in the First Plastics Revolution.

  So I wish a role for DPI in the Second Revolution and well: creating platforms and taking ownership in research for closing the loops.