THE CONVERSATION

# Five synthetic materials with the power to change the world

February 4, 2015 1.01am EST

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Inside Boeing's Dreamliner: tomorrow's polymers today. Jordan Tan

The New York World's Fair of 1939-40 was one of the greatest expos the world had ever seen. Visitors to Flushing Meadow Park in Queens were invited to see the "world of tomorrow" giving them a first glimpse of wonders such as the television, the videophone and the Ford Mustang.

It was also the first chance to see nylon, the world's first fully synthetic man-made fibre. It was being sewn into pantyhose by a display of knitting machines as two models played tug of war to demonstrate the strength of the fabric. Nylon had been discovered by the Wallace Carothers' group in DuPont's research division four years earlier. It was introduced at the fair as the new hosiery "wholly fabricated from such common raw materials as coal, water and air" which could be made into filaments "as strong as steel".

Nylon stockings went on to become a huge success, of course, selling 64m pairs for DuPont in their first year alone. Nylon had qualities that were superior to those of the natural product, silk, and it soon found many useful, if sometimes less fashionable, applications. Today it is still used very widely in fabrics, upholstery, sport articles, instrument strings and automotive parts.

Nylon: left the shelves like iPhones on steroids. Rebecca Abell

Since the dawning of this new era of fully synthetic materials, the advances have been unparallelled in the history of materials. Chemists have discovered new catalysts and developed new synthetic routes to join small molecules into long polymer chains with the right properties for a particular use – the polypropylene fibres that we use in carpets for example, or hard varieties of polyethylene for making plastic bottles.

Physicists, materials scientists and engineers have also designed new processing methods and new technologies to enhance performance to create substances like super-tough substances like kevlar.

Quite rightly, we are becoming more demanding at the same time. We expect products that will further enhance the quality of our lives, but we want materials and technologies that are increasingly energy efficient, sustainable and capable of reducing global pollution. It's a challenge.

Here are five types of polymers that will shape the future.

## 1. Bioplastics

As we are often reminded, plastics do not degrade and are a very visible source of environmental pollution. To complicate things further, the building blocks of these materials, which we call monomers, are historically derived from crude oil, which is not renewable.

But this is changing. Thanks to innovations with the processes for using enzymes and catalysts, it is becoming increasingly possible to convert renewable resources such as biogas into the major building blocks for manufacturing plastics and synthetic rubbers.

These substances are sustainable because they save fossil resources. But of course this only partly solves the problem. Unless they are also biodegradable, they are still a problem for the environment.


Plastic cups that grow on trees! photokup

## 2. Plastic composites/nanocomposites

Plastic composites are the name for plastics which have been reinforced by different fibres to make them stronger or more elastic. For example you can make a polymer stronger by embedding carbon fibres, which creates a lightweight material which is ideal for modern fuel-efficient transport.

These kinds of fibre-reinforced plastics are being increasingly used, particularly in the aerospace industry (the Boeing 787 and the Airbus A360 are 50% composite). Were it not for the high costs, these materials would be used in all vehicles.

More recent additions to the field are nanocomposites, where plastics are instead reinforced with tiny particles of other substances – including graphene. These have any number of potential uses, ranging from lightweight sensors on wind turbine blades to more powerful batteries to internal body scaffolds that speed up the healing process for broken bones.

Nanocomposites will become particularly exciting if we succeed in producing them through processing methods that make it possible to design them in a very controlled manner. If we look at the structures of materials in nature, such as wood, you find they are incredibly complicated and intricate. Our current composites and nanocomposites are very unsophisticated by comparison.

## 3. Self-healing polymers

No matter how carefully we select materials for engineering applications based on their ability to withstand mechanical stresses and environmental conditions, they will inevitably fail. Ageing, degradation and loss of mechanical integrity due to impact or fatigue are all contributing factors. Not only is this very costly, it can be disastrous, as was the case with the Deepwater Horizon explosion in the Gulf of Mexico in 2010 for instance.

Inspired by biological systems, new materials are being developed which are able to heal in response to what would be traditionally considered irreversible damage. Polymers are not the only materials with the potential for self-healing, but they seem to be very good at it. Within a few years since their first discovery around the turn of the century, many innovative healing systems have been proposed.

What is still incredibly challenging is the idea of extending these concepts to large-volume applications, since self-healing polymers demand much more complicated design than previous generations of polymers. But this seems the ultimate route towards long-lasting, fault-tolerant materials that can be used for products including coatings, electronics and transport.

## 4. Plastic electronics

Most polymers are insulators and therefore don't conduct electricity. However an upsurge in this field of polymer research emerged in 2000 after the award of a Nobel Prize to Alan MacDiarmid, Alan Heeger and Hideki Shirakawa for work on discovering that a polymer named polyacetylene became conductive when impurities were introduced through a process known as doping.

Not only does the same process make other similar polymers conductive, some can even be converted into light-emitting diodes (LEDs), raising the prospect of flexible computer screens like the one below.


Flexible screen display by Plastic Logic Plastic Logic, CC BY-SA

This is an area where polymers still face considerable challenge and strong competition from incumbents like silicon and organic LEDs. Still, when looking for cheap flexible replacements to existing electronic devices, polymers have much to offer as they can be easily processed in solutions and can be 3D-printed.

There seems to be enormous research going on in this area, with polymers sometimes playing the role of the active component, such as in semiconductors, and sometimes acting as a vehicle for other substances, such as in conductive inks.

## 5. Smart and reactive polymers

Gels and synthetic rubbers can easily adjust their shape in response to external stimuli, which means they are able to respond to changes in their surroundings. The external stimulus would usually be a change in temperature or acidity/alkalinity but it could equally be light, ultrasound or chemical agents. This turns out to be incredibly useful in designing smart materials for sensors, drug delivery devices and many other applications.

You can greatly extend a polymer’s natural ability to respond to such stimuli by designing them with this purpose in mind. Mechanophores, for example, are molecular units that can alter the properties of a polymer when they are subjected to mechanical forces. These could have any number of industrial applications, especially if self-healing technology was incorporated too.

Other possibilities for smart polymers include things like window coatings that can wash the windows when they are dirty, and medical stitches that disappear when an injury has healed.