HOW GREEN ARE PETRO-POLYMERS GOING TO BE?

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ABSTRACT

The controversy between "petro-polymers" and "green polymers" is a false one. Polymers synthesized by organisms, manipulated or not, are seen as green. Polymers based on cracker products, so called petro-polymers, are considered to be environmentally unfriendly. Arguments used in favour of "natural" polymers are: biodegradability, renewable resources, recyclability, non waste producing etc. We think that several of these arguments are incorrect or irrelevant. Furthermore, we are convinced that petro-polymers might move substantially towards a sustainable situation. It might seem strange, but the most important steps towards such a situation have to be made not in the field of petro-polymers themselves but in the domain of energy supply.

1. SUSTAINABILITY

The future of the polymeric materials is determined by an interplay between the needs of society and the opportunities created by science and technology. One of the main driving forces to be expected from society in the near future is environmental friendliness. Quite some research is performed to anticipate to this. Lots of efforts are dedicated to the development of biopolymers with acceptable properties and processability, so called "green" polymers.
What exactly do we mean with "green" or "environmental friendliness" ?
The buzz-word is "sustainability". According to the World Commission on Environment and Development, "sustainable" means that we will have to fulfil our needs without compromising the ability of future generations to fulfil their own needs. In fact it means that we should not exhaust the natural resources of this planet. In other words: we will have to move to renewable resources or develop closed loops as well in energy supply as in raw material supply.
One of the troublesome cycles is clearly that of carbon. Increasing amounts of CO_2 in the atmosphere and exhaustion of the reserves of oil and natural gas are two important problems in this cycle.

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In this respect, for the majority of the present products and processes, sustainability could be translated into: CO_2-neutrality. A product or a process should, during its lifetime not emit more CO_2 into the air than it absorbs.
Biopolymers are built up by organisms by using CO_2 out of the air and in this way they are essentially CO_2-neutral. But their properties do not match in any way yet those of the petro-polymers. One can wonder whether a sustainable situation (CO_2-neutrality) could be approached with petro-polymers.

2. A SHIFT IN ENERGY SOURCE

By far the most important step forward would be a change in our energy supply.
At this moment we are burning about 93% of our oil for heating and transport. Only 7% is used as a raw material, 4% in materials and 3% in chemicals.
There is a lot to do about recycling of the 4% that is used in materials. Although this is an important item, it is clear that this discussion is of secondary importance as long as we are burning 93% of the oil.
A shift from burning oil and natural gas to alternative energy sources, so that oil and natural gas can be destined as raw materials for polymers and chemicals, is the most important change to be expected in the next century.
We must hope that this change happens before these resources are exhausted.
Often the argument is used that the reserves will seem to be much bigger than estimated as an excuse to go on the way we do now. This is no argument. The burning of oil and natural gas is no sustainable way of using resources. Moreover, there are several other arguments against the use of oil and gas as an energy source by burning. Besides the increasing amounts of CO_2 in the atmosphere, there are unfavourable thermodynamical considerations about this way of converting energy and we can wonder wether it is acceptable from an environmental point of view to drag around the world huge amounts of crude oil in supertankers.

It is to be expected that in the next two decades we will try to cope with the situation by a substantial improvement in efficiency: less raw material consumption, less energy consumption, less waste production. But this will just allow to compensate for the growth. Soon enough we will face the necessity to come to real sustainability.

As long as we are burning 93% of the oil as an energy source, there are little arguments against the burning of plastic waste, on condition that we recover the energy.
As soon as a shift starts towards using oil and gas as raw materials, back to feedstock recycling of plastic waste will become obvious. It will take more than 25 years before we are that far.

3. DOES OUR ECONOMIC SYSTEM ALLOW FOR SUCH A CHANGE?

Sustainability might become an important driving force for developments but we should not be too naive about the mechanism of the market. One can wonder whether our present economic system allows for sustainable developments.
E. von Weizsacker stated that with the rights incentives, there could be a fourfold increase in resource productivity utilizing technologies already available (1). But it is doubtful whether the right incentives are there and whether they are powerful enough to make this happen.
In fact, the market does not ask yet for sustainable products. The consumer might feel a bit disturbed about all the discussions going on, but in the mean time his consumption behaviour did not change much.
N. Myers, who is a real advocate of the "limits to growth" sees sustainable consumption as an alternative to endless economic growth fuelled by endless consumption (2). He states that economic expansion of the conventional sort is not necessarily congruent with human development.
This point of view is severely challenged by Vincent and Panayotou (3), who are convinced that the root cause of environmental degradation is not the level of consumption but rather market and policy failures that cause consumers and producers to ignore the full social costs of their decisions.
I tend to agree with them that it is not the level of consumption that causes the problem, but I doubt whether the market will induce a correction without first running into serious problems. And these problems might appear soon as a rather sudden shock.
Let us consider the following. There are about 2,7 billion people in Asia, together in India, China and the Rim countries, who will be striving in the next decades to acquire the same prosperity as the people in the western world. Even if only 30% of them will succeed in doing so, this is a lot more than the EC and NAFTA population together. If this has to be achieved with existing technologies, we clearly will run into trouble as well in energy consumption as in waste production. As far as traffic is concerned, they are already facing major problems.
Furthermore, one must be aware of the fact that a shift in energy source would also imply a major shift in economic power, as the oil companies are among the most powerful organisations on this planet. Although they have been preparing for this kind of change, one can not expect that this will happen smoothly.

4. WHAT ABOUT THE ALTERNATIVES?

As I already stated, the developments in science and technology have to provide the opportunities for a change. Two fields of development play a predominant role in this respect: the development of devices for energy conversion from alternative sources (especially solar energy) and the development of alternative ways of transport.

Normally it takes 10 to 15 years to bring a new development from lab scale to a commercial success. The time between a new concept in the academic world and commercialization is even more than 20 years. Of course, in periods of crisis certain transfers can happen faster.
If one wants to know what will be commercial by 2010, one has to look around in the industrial laboratories and find out what is working on lab scale already today.
One can see that organic solar cells are in a pretty advanced stage of development already. It is not irrational to assume that efficient, durable solar cells will be in the market for acceptable prices by 2010. A shift of household energy supply towards alternative sources could start from then on. Industrial energy supply is more difficult and will go on much longer on classical sources, albeit with a lot more efficiency.

A lot of alternative ways of transport are in development too, but implementation is slow.
It is clear that our way of transporting goods by trucks has passed the bounds of insanity. We will have to look into alternatives, e.g. transport through tubes, pipes, tunnels, etc.
There is a trend to put limits to all kinds of traffic at this moment. How long can we go on with the present "car culture"? I think until the moment that the time lost in traffic jams is no longer compensated by the gain in time and pleasure offered by individual mobility. However individual mobility will remain of ultimate importance but clearly this has to go in a fundamentally different way. In fact, cars as they are made now, are rather absurd steel boxes, most of the time transporting just one person.
The combustion motor is an outdated uproarious piece of rubbish, derived from steam age technology. But it has been improved to such a level of perfection and it has been accepted so broadly, that it is very difficult to beat it with a new technology.

Since 1993 The Clean Car Program of the Partnership for a New Generation of Vehicles (PNGV) looks into new technologies. In 1997, a choice was to be made between one of the alternatives to concentrate the efforts on. The only project on scheme was an advanced Diesel motor: the compression ignition direct injection engine (CIDI) (4).
Fortunately, the National Research Council asked to postpone this milestone, to give a chance to real non conventional alternatives. Otherwise, we would have been saddled for 50 years more with an old technology.
Clearly, the developments in this field advance too slowly and the automotive industry is not really on a new track yet. Probably because the market is not asking for it.
The electrical car still needs some breakthroughs: light weight batteries with high energy density and solar energy conversion cells might provide the necessary impulses.
The developments in communication and informatization will also play an important role in changing our ways of transport. One can think of reduction in home to work traffic, electronic coupling of cars on highways, more efficient cars, more efficient traffic, etc.

Given the present status, one can expect fundamental changes as well in energy supply as in ways of transport, after the first decade of the next century. One can however wonder whether those fields get enough attention and research budgets, in view of their importance.

5. A SECOND SHIFT TOWARDS BIOMATERIALS?

Supposing that this first shift should happen and that oil and gas will be used primarily as raw materials and that plastic waste should be recycled in a back to feedstock manner, do we attain a sustainable situation?
The situation would improve a lot, but we would still need quite some energy for the synthesis and for the recycling of materials. Depending on the amount of energy needed and on the energy source used, we might attain a more or less sustainable way of using petro-polymers.

Some people are convinced that a second shift will happen to CO_2 as a carbon source, in a direct way or via biomass. However, if the first shift could reduce the production of CO_2 to an acceptable level, this second shift is not very likely. The use of biomass as raw material for crackers to produce 'petro' polymers in this way, doesn't seem very meaningful, unless the fossile reserves would really get exhausted.

The use of genetically manipulated micro-organisms or plants to produce modified 'biopolymers' on the other hand will show a breakthrough. But most probably this will be limited to specialty polymers and polymers for niche markets. Biodegradable polymers and certain functional polymers, e.g. modified proteïns might be synthesized in this way.
In any case, nature will show, more than ever, the way to the best solutions. Nature uses a back to feedstock recycling system. Nature acts close to reversibility in this way consuming a minimum of energy. Nature developed perfect control of polymerization, supramolecular interactions and functionality. Man can make use of nature's examples in two ways. He can manipulate the highly sophisticated natural systems to force them to synthesize the polymers he wants. Or he can use the principles he learns from nature in a much simpler but broader way, using a much wider variety of chemical species, and making just one step to higher complexity by supramolecular organization. After all, one can wonder whether these two approaches are that much different in potential risk.

This field of synthetic supramolecular architectures is probably the most challenging of all. The use of these cooperative weak interactions in synthetic polymers leads to the controlled building up of 3D-structures but also introduces a new level of complexity that did not exist before which in turn can lead to new unknown functionalities. This will bring us into the field of the nanotechnology, situated between the molecular structures and the macroscopic structures.

The 21st century might be characterised by a down scaling of several functions to this nano-level, in this way solving several problems resulting from the fact that, at this moment, we are performing processes in a way that is too rude, consuming too much energy and too much raw materials and creating too much waste.
Using the principles from nature on a broader set of synthetic materials seems to be at least as promising as just using the existing biomaterials themselves.

6. CONCLUSIONS

The first decade of the 21st century will be characterized by a tremendous improvement in efficiency: less raw material consumption, less energy consumption, less waste production. Electronics and informatization will play an important role in this. This will lead to a new way of thinking about polymeric materials: longer life cycles, more life cycles, defined life cycles, better skin properties, 'aging with dignity'. Energy recovery is the obvious way of recycling in this period.

In the second decade, hopefully a shift in energy source from oil and gas to alternative sources will start. This will eventually lead to the sustainable use of oil and gas as raw materials. Back to feedstock recycling of materials will become obvious by then.

A second shift towards biomass as raw material or towards biopolymers is not likely. Biopolymers will however be used as specialties and in niche markets.

Nature shows the way in every respect:
* ultimate control over polymerization
* using supramolecular interactions in many ways, e.g. for information storage
* creating polymers with very specific functions
* not violating thermodynamics

Man wants to apply the principles of nature in a much broader way. That's the way he learns. The question is always how far he can go in maximalizing the learning effect while keeping the chance of causing catastrophies within acceptable limits.

7. REFERENCES

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(4) Eliot Marshall, Science 276, p. 104 (1997)