PLASTICS RECYCLING by **Dr Ron Bennett** on 19 May 2020

Dr Bennett began by showing a rising graph by McKinsey of worldwide production of plastics to 2050 – noting that in 2030 there would be a demand for 560 Mtonne/year, of which 460 Mtonne would become waste. The demand figure for 2050 was 1800 Mtonne/year, five times the present amount.

1 PETE	Polyethylene Terephthalate (PETE or PET)
2 HDPE	High-density Polyethylene (HDPE)
3 V	Polyvinyl Chloride (PVC or V)
4 LDPE	Low-density Polyethylene (LDPE)
5 PP	Polypropylene (PP)
6 PS	Polystyrene (PS)
7 OTHER	Other Plastics (OTHER or O)

Plastic Volumes, Types and Applications - There are two types of plastics:

- **Thermoplastic**: long chain molecules with no chemical bonding between the chains enabling the chains to slide past each other under stress – polythene (PE) and polypropylene (PP) are the most commonly used plastics for packaging, bottles etc.
- **Thermoset**: long chain highly cross-linked structures formed with heat, free radicals or radiation to form a rigid three dimensional network. These strong resilient materials cannot be softened by heating, but undergo thermal decomposition at high temperatures. Best example is Bakelite (a phenol-formaldehyde resin).

Elastomers: these are not defined as plastics but chemically are midway between thermoplastics and thermosets. Here the long chains are lightly cross-linked such that at ambient temperatures they can be compressed or stretched returning to their original shape on removing the distorting forces. They are used in adhesives, seals and flexible moulded items such as seals and foam mattresses and, of course, motor tyres.

Global waste and recycling rates - Plastic waste can be: Recycled, Incinerated (burnt) producing energy, or go to Landfill.
The majority of plastic is commercial – and is not recycled.
India has the highest recycling rate at 60%, next being South Korea at 45%.

In 2018 most European countries recycled between 20 & 40% of their waste, the remainder going to Landfill, or being Burnt. Switzerland, Austria with no landfill and the Scandinavian countries, with very little, burnt what was not recycled; Greece put all its surplus waste in landfill. The UK figures were 33% recycled, 45% burnt and 22% landfill.

Some 8% of clothing was passed on; 10% was recycled; 25% was incinerated; and 57% went to landfill.

Plastics into the Rivers and Oceans – whether large pieces or microplastics. When measured in Mtonne/year the latter looks tiny, but may be more damaging environmentally, though the large pieces break down eventually. North America deals best with the large pieces, at 0.07 Mtonne/year, but produces 0.26 of microplastics; China's figures are 2.21 & 0.24, with India and Africa not far behind. Europe's are 0.28 & 0.24.

Microfibres, less than 10μm dia are shed while clothing is worn – and when washed, microfibres get into waste water, and are not removed by sewage treatment. The figure for a 6kg wash of acrylic clothing is 800,000 microfibres, of polyester is 500,000, and polyester-cotton blend 140,000.

Marine degradation of an LDPE bag is slow, but specially formulated PHA is 40% degraded in 180 days.

Separating & Sorting Plastics – The first stage is at home when the symbols shown above, if on the waste item, are read to see what can be put in the recycling bin. The symbols are not normally used thereafter.
At a typical Waste Centre the mixed recycling waste is progressively separated into individual items:

- The first sort is by hand, removing paper & cardboard; Metals, Plastics & Glass continue on;
- Iron/steel is removed magnetically; Aluminium is removed by eddy current induction;

- Plastics are blown off; then sorted into resin type by their optical spectral responses;
- Glass carries on, and is pulverised to cullet.

This is idealised. Other materials are in the mix, often in combination, so none of these steps works perfectly.

Plastics usually contain tiny quantities of colorants, plasticisers, flame retardants, etc. Carbon black is often used in plastic food containers, but absorbs the detecting radiation – perhaps use another (cheap) black colourant, a fluorescent dye or – what? Food wrapping often comes as a bilayer of two different plastic films.

Recycling - McKinsey, in a 2018 Report, spoke of **Mechanical recycling** where used plastic is physically processed back to resin pellets, leaving the polymer chain intact. This has been established as a viable business for PET and HDPE, but with room for further process optimization. A key challenge is finding how to preserve the performance quality of resins through recycling steps and avert the deterioration that currently occurs. This is only viable when the price of oil based resins are reasonably high.

Dr Bennett showed a 'ByFusion' process (which fits in a 12m shipping container) where incoming plastic is shredded, mixed with superheated water and compressed to form 'ByBlocks', which can be used to build walls.

Separated Plastics – the Next Step (excluding returnable reusable packaging). Based on type, purity, economics and social responsibility we can choose a route from the following:

- Low Tech Application where no chemical processing occurs and polymer does not return to original use;
- Higher technical application where a proportion returns to previous application;
- High technical processes with full return to original use;
- Process to convert to an equivalent value;
- A chemical processing step where other useful chemicals can be made;
- A chemical processing step to return to the original building blocks (full cycle);
- Reusable containers dependant on a deposit/returnable scheme.

Disposable nappy recycling: How soiled nappies can be reused.
A total of 187 billion nappies are thrown away each year, and are hard to recycle. But now engineers have devised ways of recovering the plastic and other materials inside them. Polypropylene is typically the material used for the permeable top sheet, while polyethylene is the resin of choice for the non-permeable back sheet.

A pilot plant has opened in Treviso, Italy, backed Procter & Gamble, the world's largest maker of nappies. **Thermoset Composites** - can be Mechanically recycled into powdered fillers or fibrous materials for reinforcement. Thermal methods can produce fibres but also with energy or chemical recovery.

Foamed Plastics are more difficult to treat as they are of low density and contaminated with blowing agents.

PVC – a cheap versatile material, mainly used as a building material. The chlorine poses health risks, and it is not easy to recycle as it can contain several additives, eg for a white plumbing pipe: Tin stabiliser 0.3-1% ; Paraffin Wax 0.6-1.5% ; Polythene Wax 0-0.3% ; Calcium Stearate 0.4-1.5% ; Calcium Carbonate 0-5% ; Titanium Dioxide 0.5-3% ; Process Aid 0-2 %.

Chemical Recycling – There are several processes at pilot stage, which can all Decontaminate the feedstock:

METHOD	FEEDSTOCK	MIXED	OUTPUT
Solvent Based Purification	PVC, PS, PE, PP	No	Polymer
Chemical Depolymerisation	PET, PU, PA, PLA, PC, PHA, PEF	No	Monomers
Thermal Depolymerisation (Pyrolysis)	PMMA, PS	No	Monomers
Cracking (Pyrolysis & Gasification)	Plastic Mix	Yes	Hydrocarbon Mix

Unilever has piloted the CreaSolv process in Indonesia to recover PE from multilayer flexible sachets. The recovered flexible plastic is used to make new sachets.

APK in Germany is recovering near virgin quality PE and PA (Nylon) from multilayer film waste.

Three solvents at different temperatures can be used for separation:	POLYMER	TETRAHYDROFURAN	TOLUENE	ZYLENE
	PVC	Room	Not Soluble	138^{0}C
	PS	Room	Room	Room
	PP	160^{0}C	105^{0}C	118^{0}C
	LDPE	65^{0}C	50^{0}C	75^{0}C
	HDPE	160^{0}C	105^{0}C	105^{0}C
	PET	190^{0}C	Not Soluble	Not Soluble

Other processes are aimed at other products: one is PET to Jet Fuel.
Light olefins made from Polythene in two-step process – pyrolysis & cracking: a good feed for chemical plant.

- At 500^{0}C – 93% C21+ waxes and C12-C21 hydrocarbons;
- At 800-950^{0}C (residence time <0.1sec) yield of C2-C4 olefins is 77% and aromatics 6%.
- PP can be cracked and gives more aromatics and branched chains.

Waste Plastics depolymerisation (“cracking”) by Fast Pyrolysis and in Line Catalytic Steam Reforming for Hydrogen Production.

The Plastics Players each with different Motives:

- Oil Companies – moving into chemicals;
- Chemical Companies / Resin Producers – want to sell chemicals;
- Processors – have to weigh quality v price (would rather use virgin plastic);
- Brands- want to promote their green credentials;
- Governments – how will they implement change without upsetting consumers (and voters!);6
- Consumers – will they pay and will they accept rational solutions.

Taxation could be used to deter non-recyclability.