DEVELOPMENTS IN END-OF-LIFE TECHNOLOGIES FOR FLEXIBLE PACKAGING: MULTILAYER FILMS, BARRIER STRUCTURES AND POUCHES

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OUTLINE

1) Advantages of flexible and pouch packaging over other packaging formats

2) Difficulty of end-of-life mechanical recycling, reuse and/or recovery of flexible, barrier and pouch packaging and why this is important

1) Industry actions and responses to obviate end-of-life challenges

2) Development of new recycling and recovery systems and package materials and structures

3) Conclusions, future developments and summary
Flexible packaging is very successful and is replacing other formats because of its resource efficiency:

- Provides equal or better functionality than other formats but uses far less materials (and generates less waste), less energy and transport costs than other formats
- Has lower environmental impact (LCA) and carbon footprint (GHG emissions) than other formats
- High and tunable barrier protection minimizes content spoilage and product waste and increases shelf-life, particularly for foodstuffs
- Consumer convenience fits with contemporary lifestyle, e.g. easy opening and portion control
- Replacing all non-flexible packaging with flexpack would remove 26mtpa from waste stream, ca. 77% reduction
FLEXIBLE PACKAGING NEGATIVE FACTORS

The challenge is at End-of-Life because of problems of disposal, recycling, reuse, littering and ocean pollution:

- Difficult to mechanically recycle films and multilayers, particularly post-consumer, in present MRF equipment so they generally end up in landfill
- Low bulk density so less economic incentive
- Printing and frequently food residue contamination, often 10-20% of package weight
- High visibility as litter even though uses less material

These are significant problems due to consumer, NGO and governmental environmental and sustainability concerns and opposition and potential regulatory action, e.g. movements in California, Europe and elsewhere to restrict, tax or ban “single-use” flexible packaging
INDUSTRY ACTIONS AND RESPONSES

Industry serious about ecological challenges & actively seeking effective, economic end-of-life solutions to keep flexible packaging from landfill, litter and ocean pollution.

Companies and brands are setting goals for sustainability and levels of recycle content in flexible and other packaging.

Industry recognizes it is vital to further increase flexible packaging resource efficiency with improved and optimized end-of-life waste management, recycling and recovery systems, materials and designs. Multiple approaches are under investigation.
NEW TECHNOLOGIES FOR END-OF-LIFE PROCESSES FOR FLEXIBLE PACKAGING

Major approaches:

- Enhanced mechanical recycling technology and collection, identification, marking and sorting systems, e.g. Materials Recovery for the Future, EU CEFLEX project

- Improved materials and designs for recyclability and development of mechanically-recyclable mono-material and coated barrier systems and compatibilizers to replace multilayer structures

- Delamination and selective extraction processes for multilayer films to economically separate & recover film polymers & materials

- Depolymerization and chemical recycling to revert polymers to monomers/feedstocks which are converted back into new materials

- Anaerobic gasification and pyrolytic waste-to-energy, waste-to-liquid fuel, waste-to-chemicals and waste-to-monomers processes
MATERIALS RECOVERY FOR THE FUTURE

- Consortium of brand owners, packaging companies and packaging industry organizations, led by American Chemistry Council
- Sponsors: Dow, Pepsico, LyondellBasell, Plum Organics, P&G, Nestle, Sealed Air, S.C. Johnson, Amcor, APR, FPA, Target, ChevronPhillips, Van Dyk, Canadian PIA and PLASTICS
- Goal to increase recycling rates, divert flexible packaging from landfill and create mainstream recovery processes and systems
- Resource Recycling Systems (RRS) research shows modifications of existing sorting technology, e.g. screens and optical scanners, can efficiently identify & sort FPP to provide a new recovered materials stream while improving quality of other streams
- Joint development program with J.P. Mascaro to demonstrate technical & economic feasibility for single-stream municipal residential curbside recycling of flexible plastic packaging at a MRF in PA and identify recyclate end-use markets
CEFLEX PROJECT (EUROPE)

- Collaborative consortium project of 140+ companies and organizations representing entire European flexible packaging value chain
- Project goals by 2025:
  - To make flexible packaging sustainable, more valuable in the circular economy and have end-of-life value, a major challenge today
  - Increase European collection and recycling of flexible packaging
  - Develop design guidelines for flexible packaging and for end-of-life collection, sorting, recycling and recovery systems and infrastructure
  - Maximize overall resource efficiency and optimize recyclability (mechanical, chemical and other recycling types)
  - Ensure that flexible packaging materials stay in the circular economy and do not become marine litter
  - Ensure that flexible packaging is actually recycled and that the recyclates find sustainable end markets to replace virgin materials
- D4ACE guidelines (Designing For a Circular Economy) have now been developed which are being endorsed by the whole 140+ CEFLEX stakeholders and already being implemented
The Stakeholders

MATERIAL PRODUCERS

FLEXIBLE PACKAGING CONVERTERS

BRAND OWNERS AND RETAILERS

COLLECTORS, SORTERS AND RECYCLERS

SUPPLIERS, END USERS AND OTHERS

www.CEFLEX.eu
STRUCTURE OF FLEXIBLE PACKAGING

- Flexible packaging can be monolayer, coated monolayer or multilayer
- The layers are different materials with specific functions in the structure and can include outer “bulk” layers, barrier layers, tie layers and seal layers
- These layers and the film structure cause the difficulty in mechanical recycling
DEVELOPMENT OF SINGLE POLYMER BARRIER AND POUCH MATERIALS

- Cost effective all-PE replacements for non-mechanically recyclable PET/PE and other mixed material laminates and pouches, processable on conventional conversion and packaging equipment
- Structures designed for mechanically-recyclable barrier and pouch packaging using single polymer material complying with the “How2Recycle” store drop-off recycling programs developed through collaboration with the Sustainable Packaging Coalition
- Nova Chemicals “I-Beam” structures with enhanced moisture and oxygen barrier properties acceptable for food packaging, good optical properties, higher stiffness, puncture resistance, and sealability: (sLLDPE)/(“Surpass” HDPE)/(LLDPE)/(“Surpass” HDPE)/(C8LLDPE)
- Dow “RecycleReady” technology using HDPE and “INNATE” single-site LLDPE material structures. High stiffness and toughness, more puncture- and tear-resistant than PET/PE, lower MVTR. High oxygen barrier can be incorporated with an EVOH layer
- LyondellBasell and Borealis nucleated-HDPE and –PP improved water vapor barrier layer and enhanced downgauging
Replace Existing Structure with Store Drop-off Recyclable Film

Non-recyclable Structure (Multi-material)

- PET AIOx
- Ink / Adhesive
- PE

Not recyclable due to mixed materials

RecycleReady Structure (Mono-material)

- Printability
- Stiffness, moisture barrier
- Low temperature activation, zipper compatible
- Heat resistance
- High gloss and clarity
- Oxygen barrier
- Hermetic seals

Source: DOW

Designing for Recyclability “RecycleReady”
Compatibilizers are molecules containing different functional groups to aid recovery of incompatible polymers in multilayer packaging film systems and mixed plastics.

Dow Chemical “RETAI“ Technology for PE/EVOH barrier systems as part of “RecycleReady” Program. Enables production of barrier packages and pouches that can be mechanically recycled in a PE recycling stream. Also works for PA barrier layers but this is not yet qualified for store dropoff program.

The compatibilizer is incorporated into an HDPE layer. Upon recycling of the multilayer film, the compatibilizer disperses the EVOH or PA in the PE in very small domains (below wavelength of visible light) so that the PE is still transparent and can be reused although the EVOH or PA is no longer present as a barrier layer.

Dow collaboration with Kellogg for dry food pouch packaging.
DEVELOPMENT OF BARRIER COATINGS AND ADHESIVES TO REPLACE POLYMER LAYERS

- Development of effective barrier layers which do not interfere with mechanical recycling
- Barrier coatings, adhesives and tie layers can be extremely thin (a few nm) and not compromise mechanical recyclability while providing an enhanced or impenetrable oxygen barrier and allowing lightweighting and reduction in number of layers

Some examples are:
- SiOx-, AlOx- and amorphous carbon-nanocoated polyolefins, polyesters and polyamides, e.g. Amcor “Ceramis” and Toppan GL
- Nanoclay composite-coated and acrylate-coated polymer films
- Nano-fibrillated and nanocrystalline cellulose coatings

- BUT there are still the problems of collection and sorting to separate and recycle pouches mechanically, and of film contamination, particularly food waste, since it is hard to get clean postconsumer film for mechanical recycling
DELAMINATION, DEPOLYMERIZATION, CHEMICAL AND PYROLYTIC RECYCLING PROCESSES

- Delamination and selective extraction
  - Original polymer structure essentially retained

- Depolymerization and chemical recycling processes
  - Original polymers broken down into monomers or other feedstocks which can be repolymerized or incorporated into new materials

- Gasification and Pyrolytic Processes
  - Original polymers broken down to syngas (CO + H₂) or monomers or further converted into chemicals, hydrocarbons or fuels

- CEFIC (European Chemical Industry Council) anticipates that EU will recognize chemical recycling as a legal, valid waste management option under the Packaging Waste Regulations in addition to mechanical recycling and energy recovery
SAPERATEC DELAMINATION PROCESS

- Low-energy mechanical recycling process for multilayer packaging
- After initial shredding step, proprietary surfactant-based microemulsions are used to break up and separate the layers
- The microemulsion is then reusable
- Works with formats incorporating plastics, paper and aluminum (e.g. PE/Al, PP/Al, PE/PET)
- High purity plastic components, aluminum and cellulosic fibers can be separated out for reuse
- Originally developed for rigid packaging such as beverage cartons, but now being extended to flexible systems
- Pilot plant in operation in Germany since 2014 and first large scale recycling center (18ktpa) scheduled after funding round
- Still have challenge of collection and sorting barrier packaging in requisite volumes
SELECTIVE EXTRACTION PROCESSES

- APK AG “Newcycling” chemical dissolution process
  - For multilayer and mixed plastics to yield polymers with properties close to virgin materials & with competitive economics
    - Proprietary solvent technology separates the different polymer types. Solvent is recovered and reused
    - Polymers are dissolved out, recovered from solution and pelletized.
    - First pre-commercial startup in 2019 in Germany producing LDPE, PA and Al. More plants planned for southeast Asia. CEFLEX partner

- Fraunhofer “CreaSolv” process
  - Target polymers selectively dissolved from plastic waste, any contaminants removed and the polymer reprecipitated
  - Customized solvent formulations for a wide range of plastic wastes and target polymers. Used solvents are recycled
  - Purified polymer recyclates have properties akin to virgin polymers
  - Presently less advanced than APK but supported by Unilever
Advanced circular recycling technologies for polyester waste, including food packaging and low-quality feedstocks not currently mechanically-recyclable. Prevents diversion of these wastes to landfill.

Processes work for colored, filled, dirty and food-contaminated post-consumer polyesters. No washing or sorting required.

Polyesters broken down into parent monomers which can be repolymerized into high-quality polyester suitable for food contact.
DEPOLYMERIZATION PROCESSES FOR POLYESTERS

■ IBM VOLCAT PROCESS
■ Volatile organocatalyst digests plastic waste, particularly PET, at 200°C under pressure.
■ Fast and selective. PET converted back to monomers and contaminants separated out.
■ Inexpensive catalyst easily recovered and reused as are all other chemicals used (no waste)

■ IONIQA/UNILEVER/INDORAMA/COCA-COLA PROCESS
■ Catalytic PET conversion to monomers which can be repolymerized to PET with equal quality to virgin and competitive economics
■ 10 Ktpa industrial plant in operation in the Netherlands.

■ EASTMAN METHANOLYSIS PROCESS
■ Engineering feasibility study underway with goal to have a full-scale facility operating in 3 years
BIOCELLECTION OXIDATIVE PROCESS for polyethylene

1. Plastic shredding
   Contaminated plastic films are shredded into smaller sizes.

2. Selective oxidative decomposition
   A dual-catalyst system, which operates at <140°C and atmospheric pressure, converts plastic polymers into shorter chain molecules like oligomers and dibasic acids.

3. Distillation
   Catalyst 1 is recovered and collected and then recycled back into the system.

4. Separation
   Catalyst 2, oligomers, and dibasic acids are separated by filtration; catalyst 2 is then recycled back into the system.

5. Product collection
   The dibasic acids containing solution is collected into a separate vessel.

6. Crystallization
   Dibasic acids are crystallized from the production solution into solids and harvested.
GASIFICATION AND PYROLYTIC PROCESSES

- Controlled (starved) oxygen content or anaerobic thermal gasification, pyrolysis or plasma pyrolysis of waste materials, including packaging to produce syngas (hydrogen + carbon monoxide) or downstream chemical products.

- Advantage of most gasification and pyrolytic processes is that packaging can be mixed in with other refuse, municipal solid waste, biomass etc. This avoids the necessity to identify, sort and separate types of packaging waste and no market needs to be found for a solid plastic recyclate.

IMPORTANT NOTE:

- Vital to recognize that anaerobic gasification and pyrolysis are quite different from incineration (an aerobic process producing carbon dioxide). Gasification and pyrolysis have low emissions and greenhouse gas footprint and yield useful chemical products which can be converted back into new materials. No dioxins are produced.
ENVAL PROCESS

- Provides environmentally favorable end-of-life process for complete recycling of barrier packaging, pouches and tubes based on plastic/aluminum laminates
- Construction of commercial-scale plant supported by Nestle, Kraft and Mondelez
- Uses continuous anaerobic microwave-induced pyrolysis of shredded laminate over a carbon bed, reaching temperatures of over 1,000°C, to recover 100% of clean aluminum from barrier flexible packaging ready for reuse
- Plastic components are converted to fuel gas, used to power the process, and higher alkane liquids (similar to diesel fuel)
- ENVAL won UK Small and Medium Enterprise (SME) National Green Business Award for 2017
- Still have challenge of collection and sorting Al-based barrier packaging in requisite volumes
WASTE-TO-ENERGY SYSTEMS

- Thermal fluidized-bed controlled-oxygen (800-2200°C) and plasma (>3,000°C) gasifiers/pyrolyzers allowing complete tar removal
- Waste converted to water, H₂ and carbon monoxide (syngas)
- Syngas can fuel turbines & fuel cells, substitute for natural gas, and be converted to liquid fuels and downstream chemicals
  - Alter NRG: Plasma pyrolysis of waste to clean syngas (CO + H₂). Units operating in China, India, Japan
  - Advanced Plasma Power: 2-stage fluid bed gasification/plasma treatment producing clean syngas. Demo unit in Reading UK.
  - Concord Blue Energy/Lockheed Martin: 2-stage anaerobic pyrolysis process. Plants in US, Japan, UK, Germany and India.
  - Enerkem: Fluidized bed gasification of waste to syngas and catalytic conversion to methanol, ethanol and downstream chemicals. 10Mtpa plant in Edmonton AB, plants planned for Quebec, Rotterdam, Spain, US, China
  - Sierra Energy: FastOx controlled-oxygen gasification of waste to clean syngas and ammonia. Plant in California
ENERKEM FLUIDIZED BED GASIFICATION PROCESS

**FEEDSTOCK PREPARATION**
- Sorting, shredding, drying (if required) and feeding
- Sorted MSW, residual biomass and other non-homogeneous waste feedstocks

**GASIFICATION**
- Conversion of carbon-rich residues into synthetic gas
  - Bubbling fluidized bed gasifier
  - Steam/Oxygen

**CLEANING & CONDITIONING**
- Primary syngas purification
  - Scrubbing towers
  - Water treatment

**CATALYTIC SYNTHESIS & PRODUCT PURIFICATION**
- Conversion of chemical-grade syngas into final renewable products
  - Catalytic reactions
  - Product purification

**Outputs**
- Ultra clean syngas (CO₂, H₂)
- BIOFUELS
- CHEMICALS
For non-polyester and mixed plastics which cannot be recycled by conventional mechanical processes, including films and flexible plastics.

- High efficiency partial oxidation (water and oxygen at high temperature and pressure) converts waste to hydrogen and carbon monoxide (syngas) which can then be converted to methanol and acetic acid.

- Pilot tests completed and commercial production planned for 2020.
WASTE-TO-FUEL, -CHEMICAL, -MONOMER AND -FEEDSTOCK SYSTEMS

- Thermal and Catalytic Processes converting plastics waste into hydrocarbons, with net energy yield. These include:
  - Agilyx/Amsty & Ineos (pyrolysis) and Pyrowave (catalytic microwave): waste PS depolymerization to styrene monomer
  - Recycling Technologies: Thermal depolymerization to low-sulfur oils and waxes using fluidized bed cracker. Pilot facility in Swindon, UK; commercial plant in Scotland to open late 2020
  - British Airways/Shell/Velocys & Fulcrum Bioenergy/BP: thermal gasification of household, plastic and other wastes to syngas, jet fuel and diesel. Facilities in US and UK.
  - Plastic2Oil and RES Polyflow/BP: waste plastic pyrolysis processes to low-sulfur diesel fuel and naphtha blendstocks
  - Fuenix/Dow: Waste plastic pyrolyzed to naphtha, paraffins and LPG
  - Lanzatech: Syngas (H2 + CO) & waste steel-plant CO converted to downstream chemicals and ethanol by gas-phase fermentation
SUMMARY

- Flexible packaging, particularly multilayer barrier and pouch packaging, has significant advantages and use has been expanding.
- Flexible packaging is ecologically advantageous (LCA) due to low materials and energy use, low carbon footprint and GHG emissions, and reduction in food waste.
- Still under attack because of difficulty of economic mechanical recycling, ocean pollution & war against “single-use” packaging.
- The food, polymer, packaging and recycling industries are responding strongly by developing:
  - Improved mechanical recycling and collection, identification, marking and sorting methods.
  - New materials and package designs (“Design for Recyclability” and incorporation of recycled components).
  - Economic new recycling and recovery methods, including delamination, dissolution and depolymerization processes and conversion to energy, liquid fuels, monomers and chemicals.
- Implementation of these various potential routes and processes will depend on local and national logistical, economic, social, legislative, regulatory and political situations, not just technological factors.
THANK YOU FOR YOUR INTEREST

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