SUSTAINABLE POLYMERS : CHALLENGES AND OPPORTUNITIES

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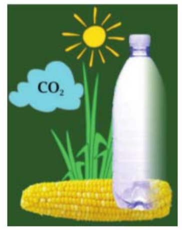
CHALLENGES TO SUSTAINABILITY

- Population and earth's carrying capacity (> 9 billion by 2030)
- Irreversible changes in global climate (+3°C ⇧)
- Providing enough food for the people (land use pattern)
- Depletion of earth resources (excessive consumption and rapid urbanization)
- Access to affordable clean energy (societal and quality of life inequities)
- Increasing burden on environment by "end-of-use" objects and materials in a "throw-away" society

Green Polymer Chemistry and Bio-based Plastics: Dreams and Reality

Rolf Mülhaupt*

Dwindling fossil resources, surging energy demand and global warming stimulate growing demand for renewable polymer products with low carbon footprint. Going well beyond the limited scope of natural polymers, biomass conversion in biorefineries and chemical carbon dioxide fixation are teamed up with highly effective tailoring, processing and recycling of polymers. "Green monomers" from biorefineries, and "renewable oil", gained from plastics' and bio wastes, render synthetic polymers renewable without impairing their property profiles and recycling. In context of biofuel production, limitations of the green economy concepts are clearly visible. Dreams and reality of "green polymers" are highlighted. Regardless of their new greenish touch, highly versatile and cost-effective polymers play an essential role in sustainable development.



1. Introduction

Modern polymer technology has green routes. In both natural and man-made technologies, polymers play a prominent role as extraordinarily versatile and diversified structural and multifunctional macromolecular materials. In 1920, the Nobel laureate Hermann Staudinger recognized that natural and man-made polymers are produced according to the same blueprint: a very large number of small monomer molecules are linked together to produce high-molecular-weight macromolecules. Properties are readily tuned by varying monomer type, sequence of monomer incorporation, polymerization processes, polymer superstructures, and processing technologies. Without polymers, modern life would be impossible because polymers secure the high quality of life and serve as pacemakers for modern technologies. During the early days of polymer sciences and engineering, almost all materials were based exclusively upon chemically modified biopolymers.[1,2] Among polymers, sugar-based cellulose, which is the major component of biomass, wood, and cotton, represents the most abundant organic compound produced by living organisms.[3] In biological cells and biotechnology labs, the incorporation of 20 amino acids is precisely controlled, producing polypeptides such as spider silk, wool, enzymes, insulin, and a great variety of other synthetic proteins for industrial and biomedical applications.[4]

In the 19th Century, natural raw materials such as casein, shellac, gum, natural rubber, and cellulose were chemically modified to convert them into useful macromolecular materials with new property profiles. An important objective was to render the infusible and frequently insoluble natural materials capable of being processed. The first horn-like plastic material was galalith, produced by reacting casein from milk (Greek *gala*) with formaldehyde to produce a stiff thermoset resin resembling stone (Greek *lithos*). Although the biodegradable and water-insoluble galalith was not moldable, sheets could be produced, thus enabling dyeing and machining. The latex of Brazilian rubber trees was collected, coagulated, dried, and vulcanized with sulfur to produce industrial rubber for making tires. Today, around 40% of rubber

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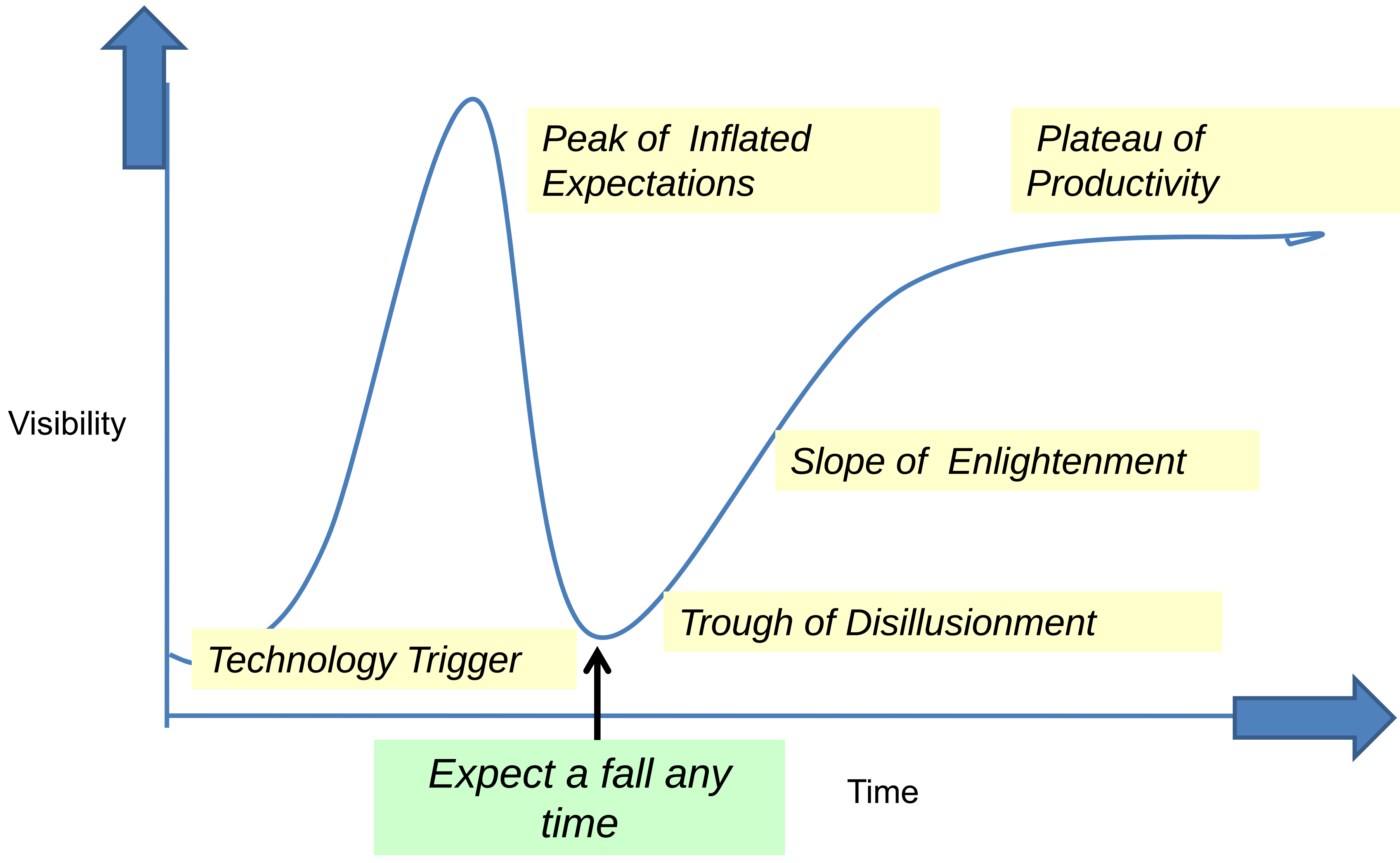
Sustainability issues of polymers and plastics is a topic of great contemporary interest occupying many pages of our scientific journals

Macromol. Chem. Phys., 214, 154 (2013)

THERE IS CONSIDERABLE HYPE AROUND SUSTAINABLE POLYMERS: WE ARE AT THE PEAK OF INFLATED EXPECTATIONS

(http://en.wikipedia.org/wiki/Hype_cycle)



SUSTAINABILITY ISSUES ASSOCIATED WITH POLYMER MATERIALS

What is the problem ?

- Use of fossil hydrocarbon derived building blocks ?

or

- After use and end of life issues?

To arrive at a solution we have to first frame the question correctly !

FOSSIL HYDROCARBON USAGE FOR POLYMERS AND CHEMICALS IS MINISCULE

Crude Oil

93%

fuel (energy)

Transportation & heating

7%

Feed-stocks

Chemicals

Polymers

Specialties

Synthesis

Pharmaceuticals

Going forward, lesser and lesser fossil fuels will be used for transportation and energy production. This will make available more hydrocarbons for converting into chemicals and materials

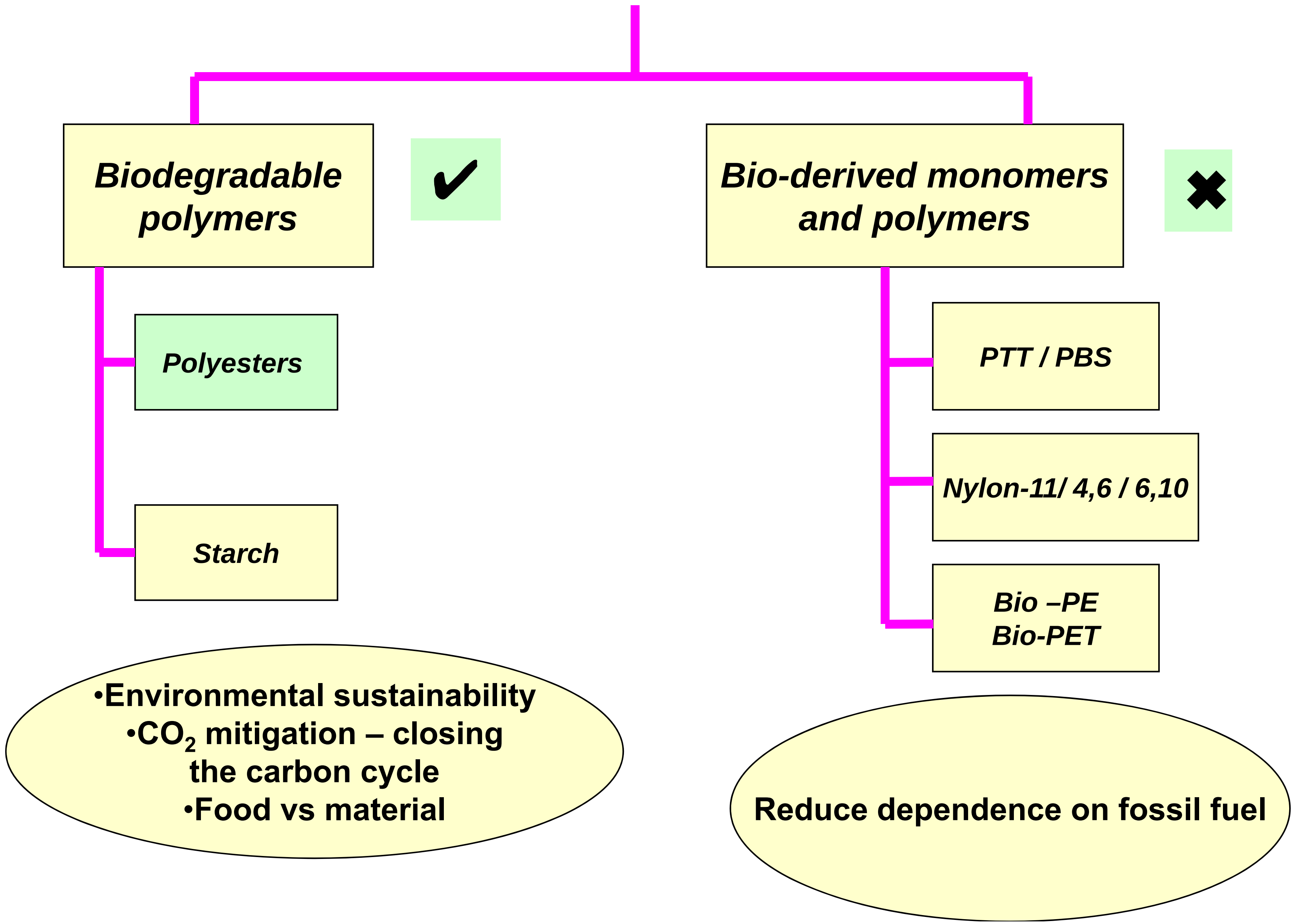
Going forward, it is unlikely that we will see a massive shift to bio-derived monomer and polymers any time soon for commodity applications. The five largest commodity polymers , PE, PP, PVC, PET and polystyrene will continue to be derived from hydrocarbons for a long long time. Polymers offer the largest value addition to fossil hydrocarbons ; more and more refineries, especially in emerging economies, will shift to petrochemicals as the demand for hydrocarbon as an automotive fuel reduces in the years to come

YET THERE IS TOO MUCH FOCUS ON BIO DERIVED MONOMERS FOR NON BIO-DEGRADABLE POLYMERS

- Of the 4 million tons of bio derived polymers currently in commercial production, 70 % are bio-based non-biodegradable polymers; hardly 30 % is truly biodegradable polymers; by 2020, this ratio will be closer to 80:20 !
- Emphasis appears to be towards replacement of fossil hydrocarbon derived monomers for polymers
- Little focus on compostable and biodegradable polymers

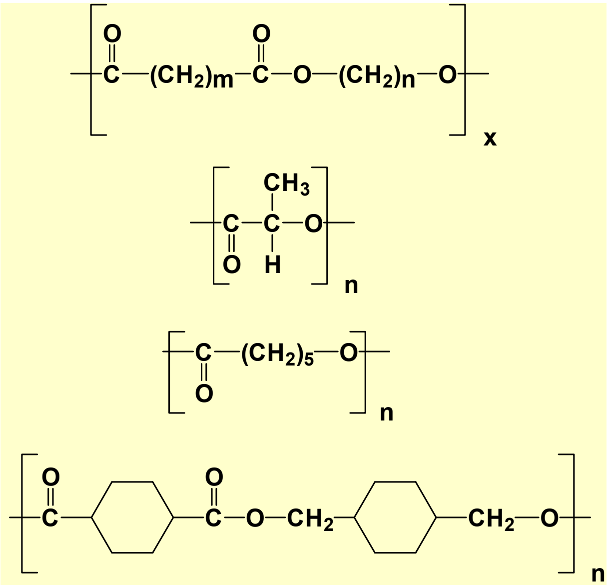
*A clear example of R&D focus that is defined by what **can be** done rather than what **needs to** be done*

POLYMERS FROM RENEWABLE RESOURCES



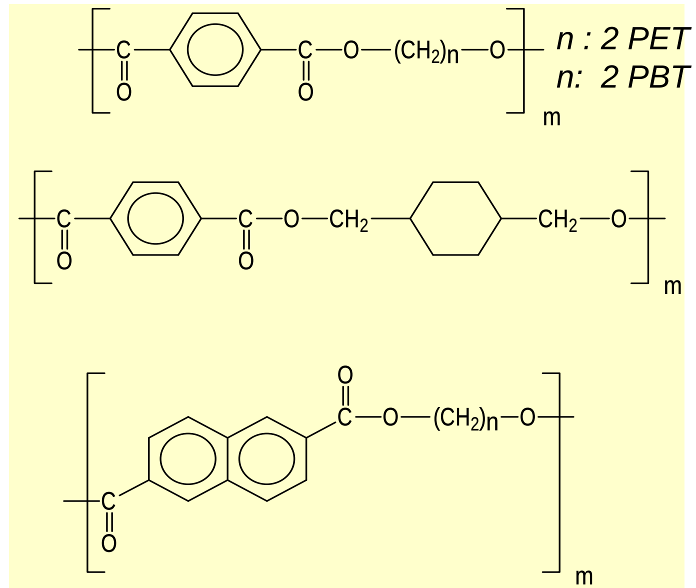
GENERAL CLASSES OF POLYESTERS

Aliphatic polyesters



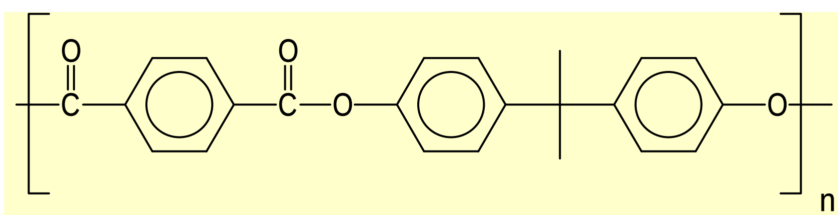
< 200,000 tons per annum !

Aliphatic-Aromatic polyesters



70 million tons per annum; 27 million tons goes for making bottles !

Fully Aromatic polyesters



ALIPHATIC POLYESTERS

- Aliphatic polyesters are the only family of polymers whose monomers are best derived from sugars
- However, their property profile requires greater diversity to meet a diverse range of applications
- There is a need for greater focus on aliphatic polyesters to create greater structural diversity
- This will require a diverse set of monomers.
- These monomers can be bio derived or hydrocarbon derived
- Irrespective of the source of the monomer , aliphatic polyesters will be biodegradable under compostable conditions

“DROP- IN” BIOPOLYMERS : DOES IT MAKE SENSE ?

- Bio PE, Bio PP, Bio PET, Bio PVC !
- All monomers derived from sugar ethanol
- Apart from competition from food large scale fermentation processes are not carbon neutral; every Kg of ethanol by fermentation results in 1 Kg of carbon dioxide
- Poor atom efficiency; starch to ethylene has an overall carbon atom efficiency of 65%; A cracker converts ethane to ethylene in > 90 % carbon atom efficiency
- Selling price of PE is $ 34 per million Btu; ethanol from corn sells at $35 per million Btu
- We will need 400 sq miles of land planted with sugar cane to set up one world scale plant of PE of 350,000 tpa
- Bio derived polymers are expensive, 10 to 100 % of petrochemical derived polymers; Braskem’s Bio-PE carries a price premium of 30 to 60% without any additional new functionality

SUGAR AS A FEEDSTOCK FOR COMMODITY MONOMERS AND POLYMERS :ARE THEY VIABLE?

INPUT CONUNDRUM

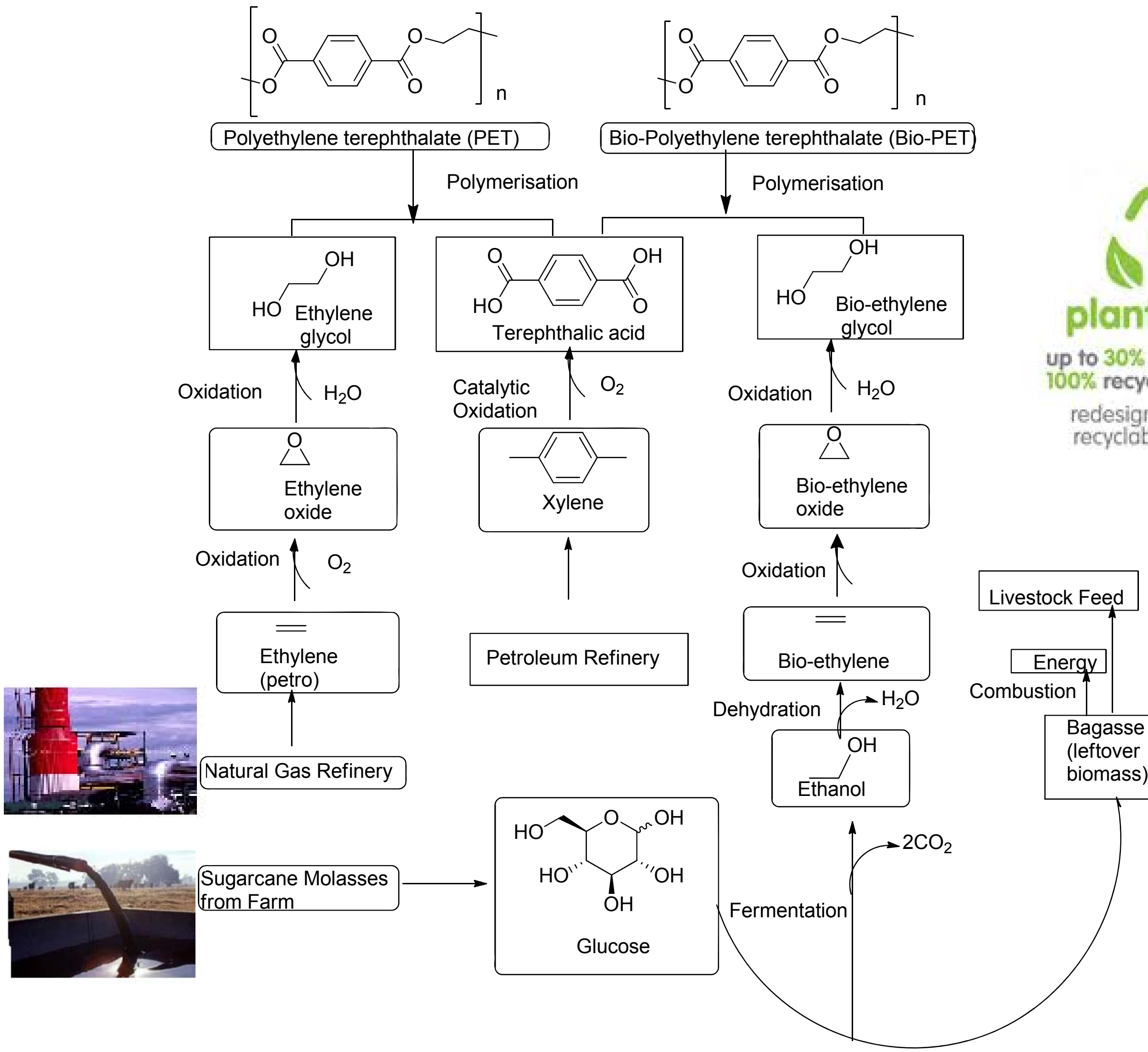
FEED-STOCK	$ per million BTU
Natural Gas	1.80
Biomass	4.0
Crude Oil	7.9
Corn	8.0
Sugar	22.6

C&EN, May 2, 2016, p.26

LIGNOCELLULOSIC BIOMASS AS A SOURCE OF SUGAR

- Sugar derived from lignocellulosic biomass is attracting increasing attention as a feedstock
- The reason is simple; we have over 180 million tons of cellulose available annually, a natural polymer on planet earth; compare this with the current production of synthetic polymers, around 400 million tpa
- Unfortunately, cellulose is rather recalcitrant and is difficult to convert to sugars.
- None of the methods of conversion of biomass to cellulose satisfy the 12 principles of Green Chemistry
- Even if such a process proves technically viable, sugars must be used to make oxygenated monomers, not hydrocarbons

BIO-PET : ARE THEY SUSTAINABLE ?



plantbottle

up to 30% plant-based
100% recyclable bottle
redesigned plastic,
recyclable as ever.

COMPARISON BY GREEN DESIGN METRICS

	Atom Economy, %	Carcinogens, kg benzene eqv/L	Non-Carcinogens, kg toluene eqv/L	Respiratory Effects, kgPM2.5 eqv/L	Ecotoxicity, kg benzene eqv/L	Cumulative Energy Demand, MJ Eqv/L	% Renewable Material	Distance of feedstocks
Polymer								
PET	80	1.1×10^{-2}	62.9	4.9×10^{-3}	5.72	123.8	0	Intern
Bio-PET	62	1.3×10^{-2}	72.7	5.7×10^{-3}	6.98	146.2	15	Intern

Environ. Sci. Technol., 44, 8264 (2010)

- Switching to renewable resources results in increases in impact categories:
  - eutrophication
  - human health impacts
  - eco-toxicity
- The impacts result from increased use of fertilizer and pesticide, increased land use requirement for agricultural production, as well as, from fermentation and other chemical processing steps

Bio-PET is not more sustainable than PET !

RANKINGS BASED ON GREEN DESIGN AND LCA

Polymer	Green Design Rank	LCA Rank
PLA (NatureWorks)	1	6
PHA (Utilizing Stover)	2	4
PHA (General)	2	8
PLA (General)	4	9
HDPE	5	2
PET	6	10
LDPE	7	3
Bio-PET	8	12
PP	9	1
PS (General purpose)	10	5
PVC	11	7
PC	12	11

Environ. Sci. Technol., 44, 8264 (2010)

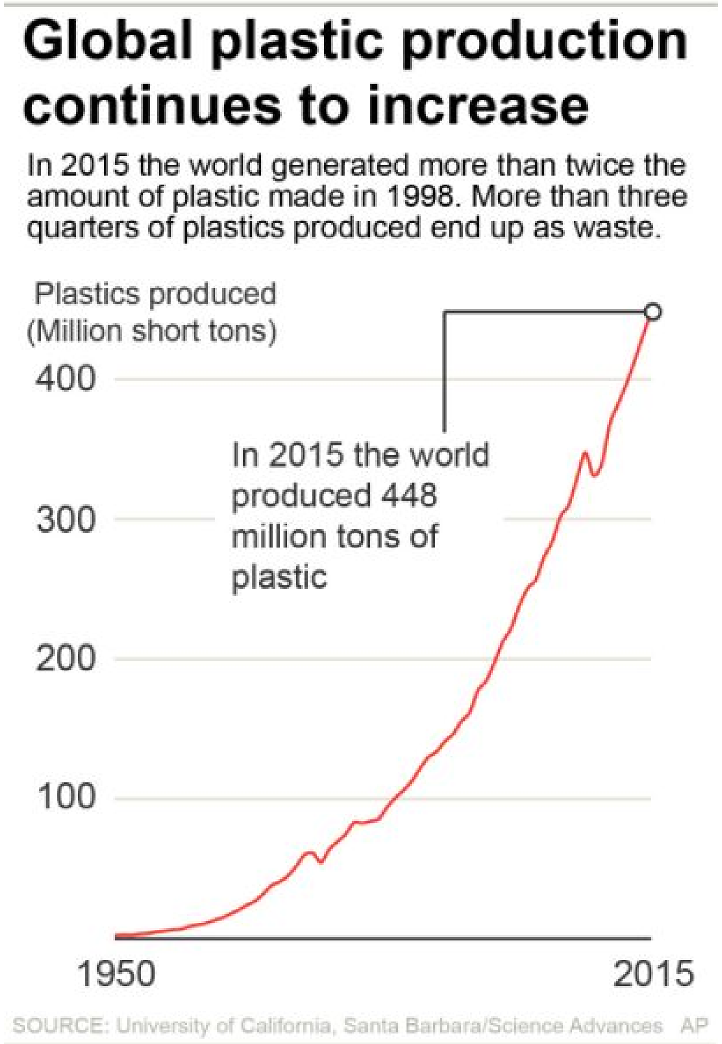
- Bio-PET ranked 8^{th} in the green design ranking and last in LCA ranking
- Production of Bio-PET requires agriculture, fermentation, and multiple chemical processing steps, resulting in low atom economy and a large potential for emissions and environmental impact

Are we managing sustainability or mere perceptions ?

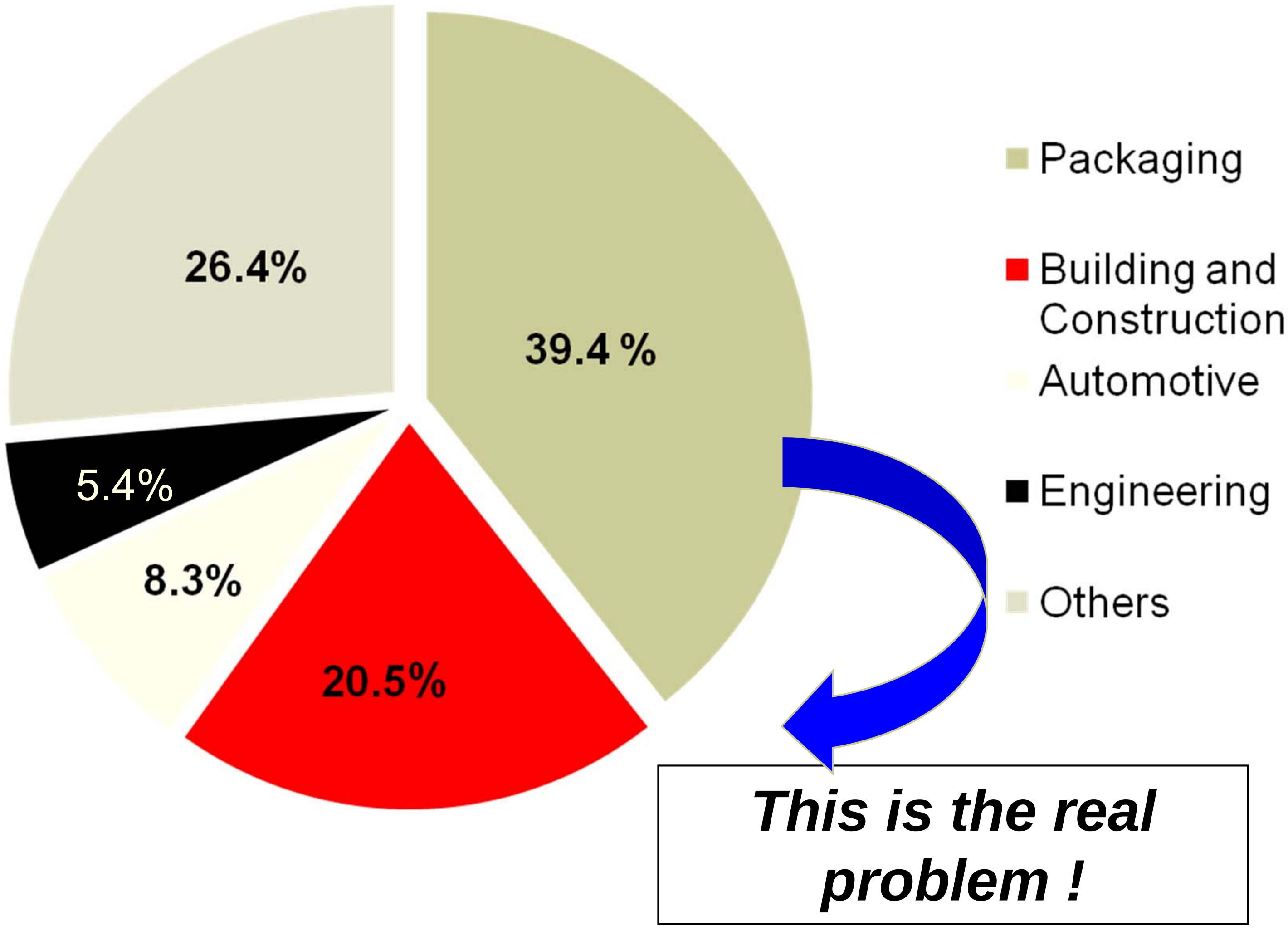
The real problem lies elsewhere, while we seem to be chasing an imaginary problem !

POLYMER MATERIALS

- Global production of polymers exceeds 400 mtpa (at a value of ~ USD I trillion) today; to double by 2035
- W. Europe consumes an average of 16 tons of materials per person per year, of which 6 tons ends up as waste, including 3 tons of landfill
- We consume 30 kg of packaging material per person per year, all of which ends up as waste
- We discard about one trillion single use plastic bags each year; generate 2 billion tons per annum of municipal waste; 13 billion plastic bottles thrown away annually
- 8 million tons of plastics leak into ocean every year; 200 million tons of plastics are already in our oceans



PLASTIC DEMAND BY APPLICATIONS



PLASTICS IN PACKAGING: BANE OR A BOON ?

Plastic packaging is taking over the supermarket, enveloping almost every food product we buy. Environmental activists say the material is causing the planet huge environmental damage and that the chemical industry should do more to make packaging easier to recycle. Industry acknowledges a need to improve but says it is combating an even bigger environmental challenge, food waste.

OUR INSATIABLE DESIRE TO CONSUME

- To date we have produced, consumed and discarded over 8 billion metric tons of plastics; 60 % have been landfilled, 30 %are still in use and 10 % incinerated (Sci. Adv., 10.1126/sciadv.1700782, 2017)
- W. Europe consumes an average of 16 tons of materials per person per year, of which 6 tons ends up as waste, including 3 tons of landfill
- We consume 30 kg of packaging material per person per year, all of which ends up as waste.
- We discard about one trillion single use plastic bags each year; generate 2 billion tons per annum of municipal waste; 5 million tons of plastics find their way into our oceans
- Global recycling rate is only about 10 % of the materials consume b

Unsustainable consumption of finite resources requires resource innovations

500 Billion bottles consumed or 7 bottles per capita

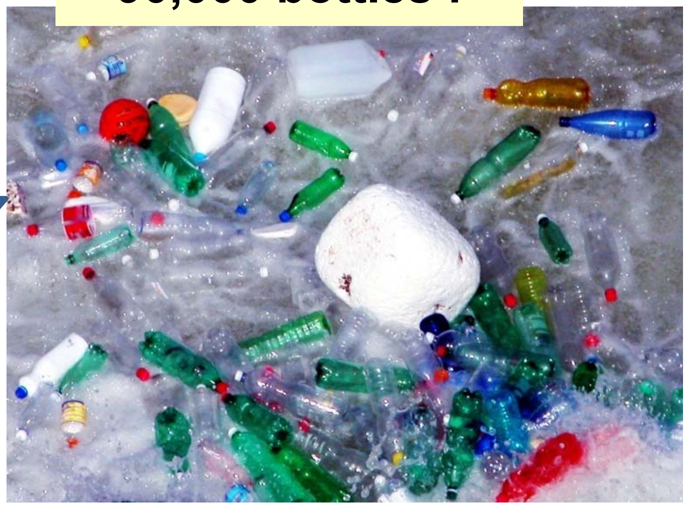
(ethylene terephthalate)

1
PETE

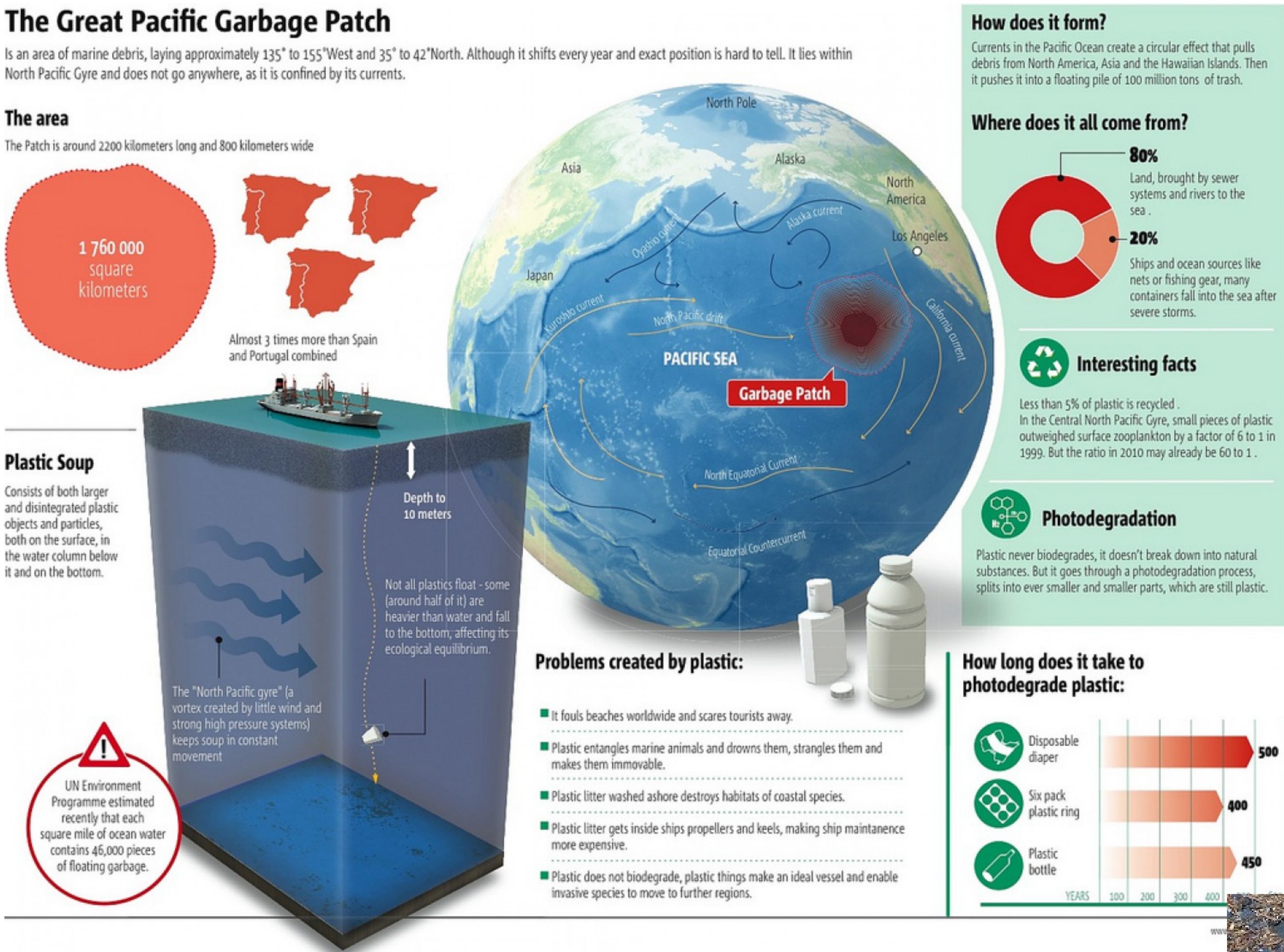
Every minute we buy one million water bottles and throw away about 90,000 bottles !

Over 30 billion liters of bottled water is consumed annually

What is the solution ?



We produce 1.2 million PET bottles every minute

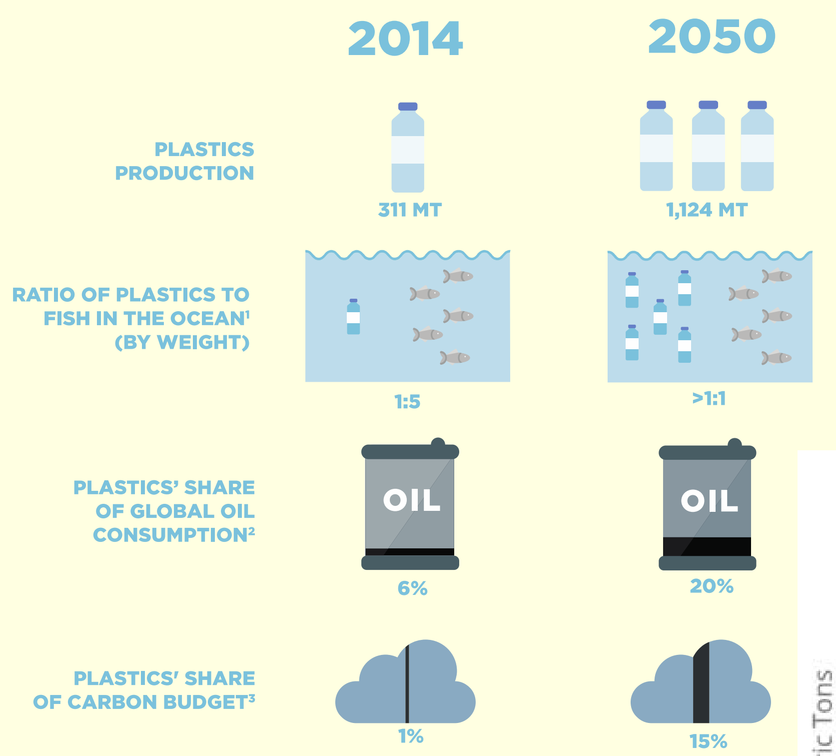


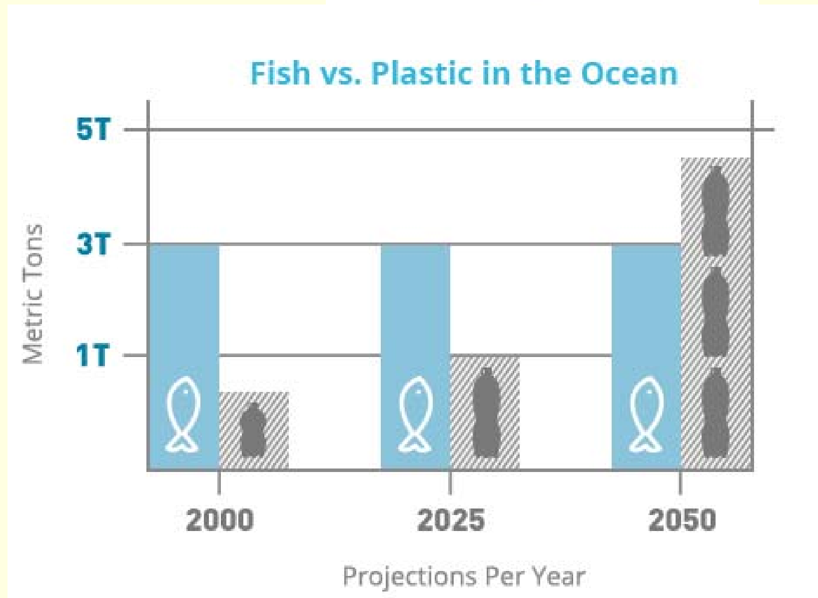
http://visual.ly/great-pacific-garbage-patch

There is an estimated 200 million tons of plastics litter in our oceans
Our oceans can be devoid of life in the not too distant future if nothing is done to stem this

The patch contains 270,000 tons of plastic waste
Microplastics upto <5 mm dia
Leachates detected : nonylphenol, Triclosan, PBDE 47 etc

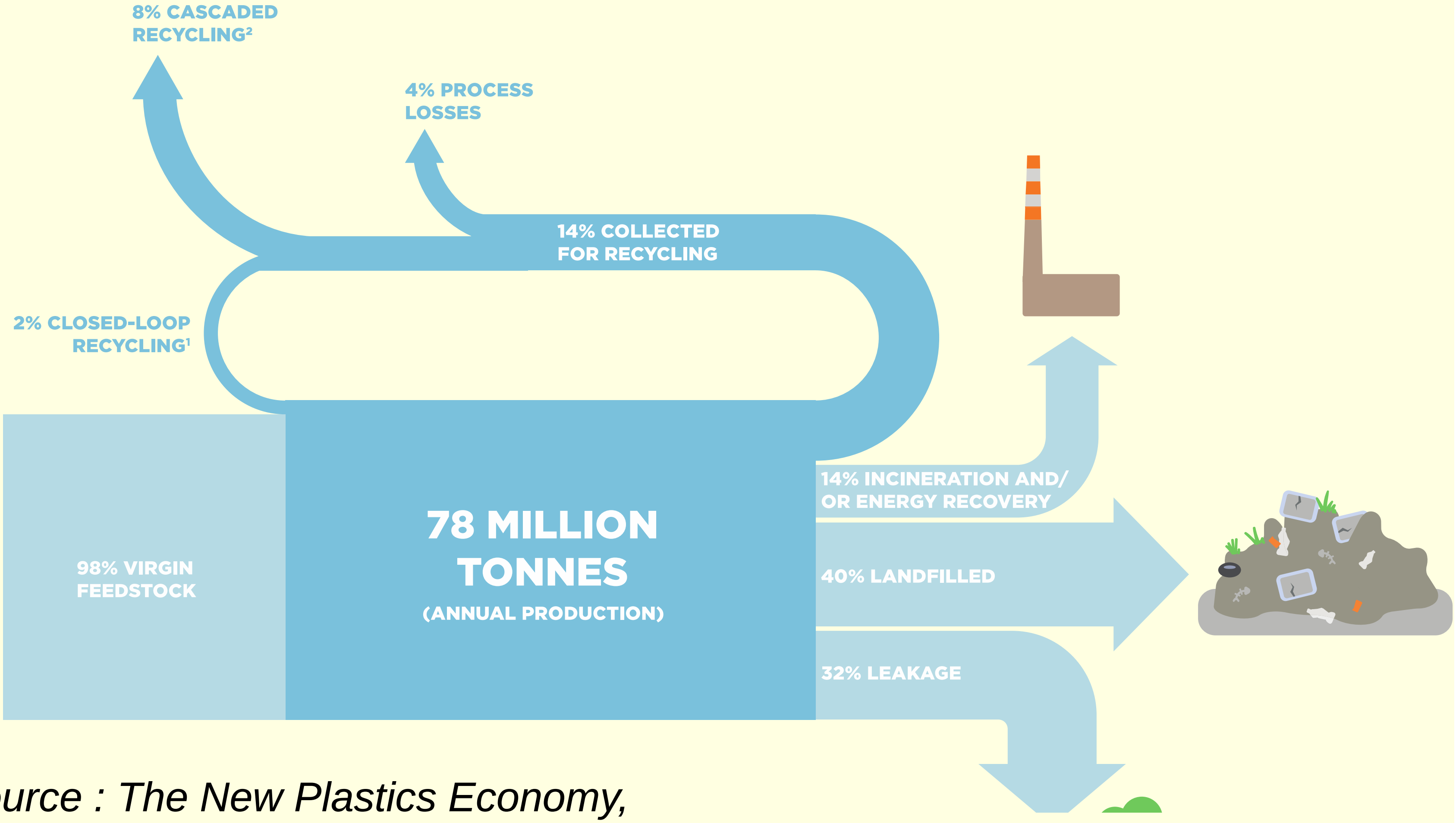
WILL THERE WILL BE MORE PLASTICS THAN FISH IN THE OCEAN ?





Source : The New Plastics Economy, The Ellen MacArthur Foundation and WEF, January 2016

ONLY 2 % OF PACAGING PLASTICS ARE SUBJECTED TO CLOSED LOOP RECYCLING



Source : The New Plastics Economy, The Ellen MacArthur Foundation and WEF, January 2016

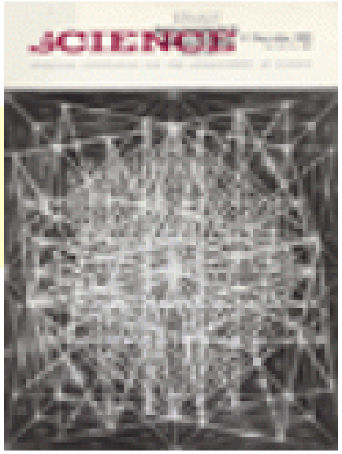
NO VIABLE RECYCLING OPTIONS FOR MANY POLYMERS AS YET !

- Two phase polymers: ABS, Impact PP, HIPS
- Multilayer coextruded films
- Polystyrene
- PVC, rigid and flexible
- Rubbers
- Polyurethanes
- Low density materials, such as foams, bubble wraps etc
- Polymers that have come in contact with food or beverages

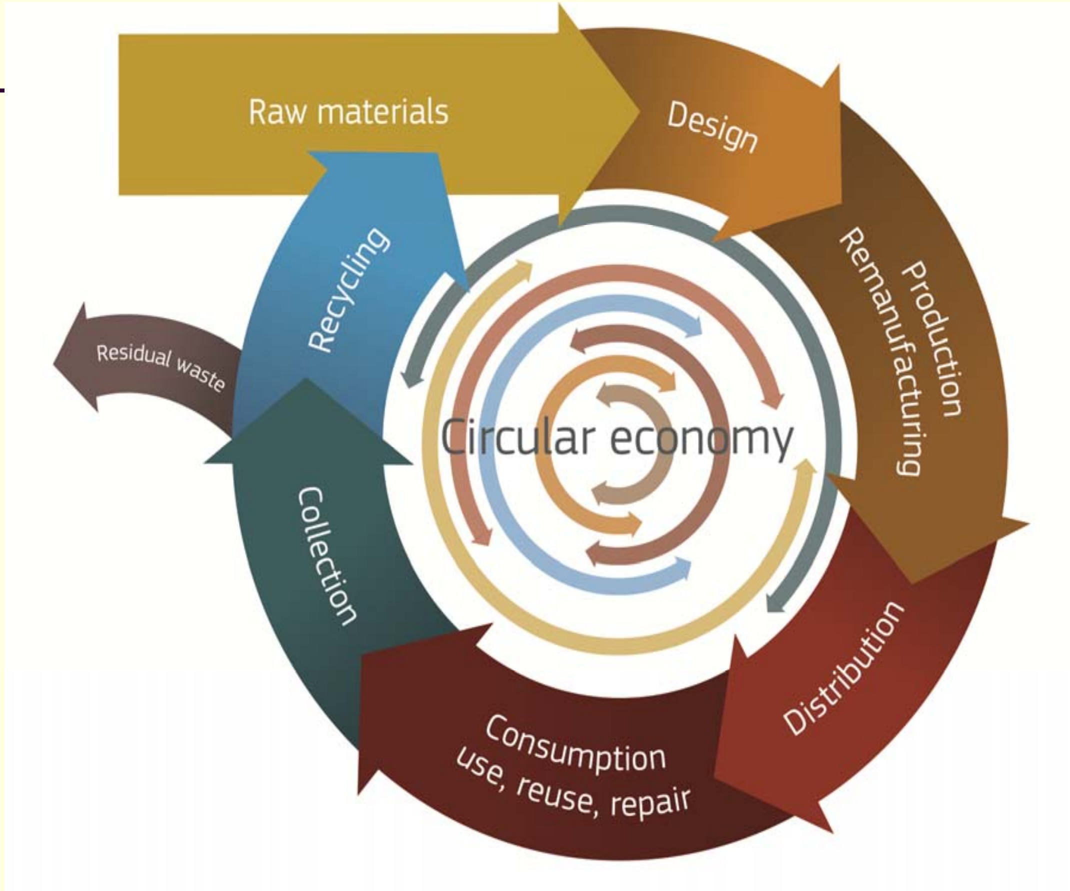
RESOURCES AND SUSTAINABILITY

- Abundance of “Cheap” resources will lead to its wasteful use (r-selection)
- Scarcity of resources will lead to more sustainable use (k-selection)
- Post industrial communities represent r-selection; but it is necessary for our survival to move to k-selection
- The easiest way to drive this process is to make resources artificially scarce, before they disappear
- This, however, flies in the face of all that we ‘know’ about how economics works : ‘Cheap’ resources are better’; in practice, the rational choices that individuals and companies make in their own self interest end up depleting the overall resource available

The Tragedy of Commons,
Garret Hardins, Science, 162(3859), 1243, 1968



THE CIRCULAR ECONOMY



2013

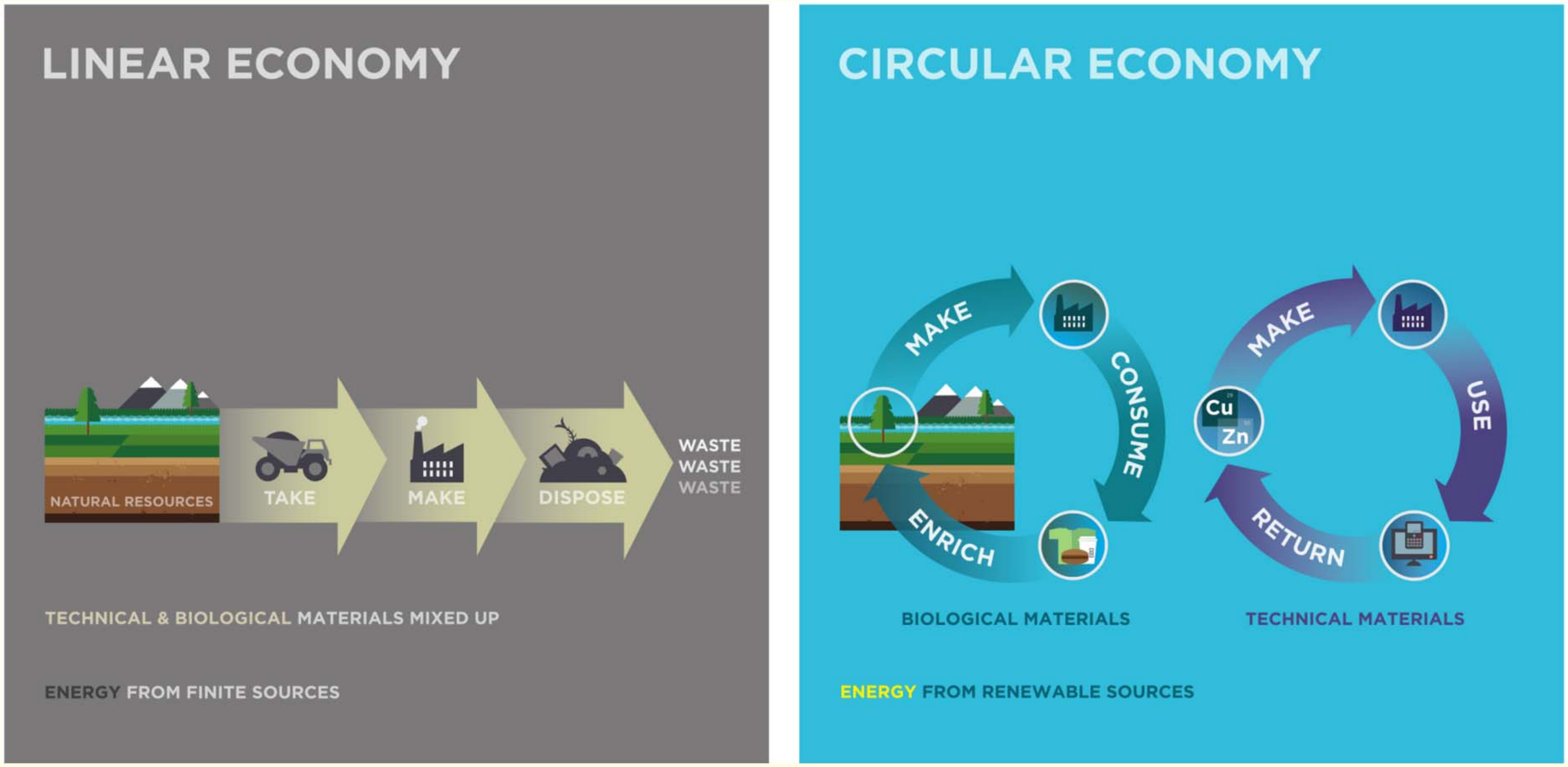
The circular economy offers the opportunity to move away from our "take - make - dispose" model, by ensuring, through careful design and innovative business models, that technical and biological materials continuously flow, safeguarding valuable resources and restoring natural capital.

CIRCULAR ECONOMY: RETHINKING THE SYSTEM

- The circular economy model is a different way to think about production and consumption that changes the linear “take, make, dispose” model to one that is restorative and regenerative by design.
- Designing and implementing circular economy processes into production and design of products and services offers significant long-term advantages.
- Circular economy models can help reduce the need for virgin materials, help find new markets for by-products, and offer better connections to consumers.

W.A. Stahel, Nature, 531, 443 , 24 March 2016

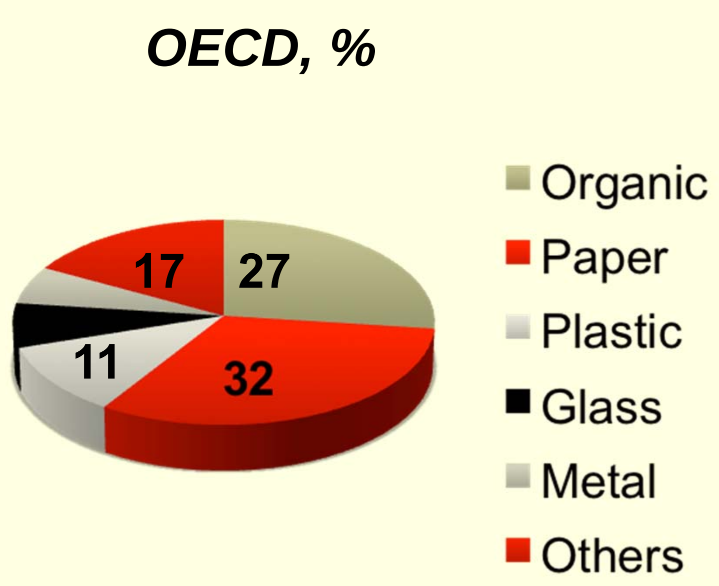
FROM A LINEAR TO A CIRCULAR ECONOMY

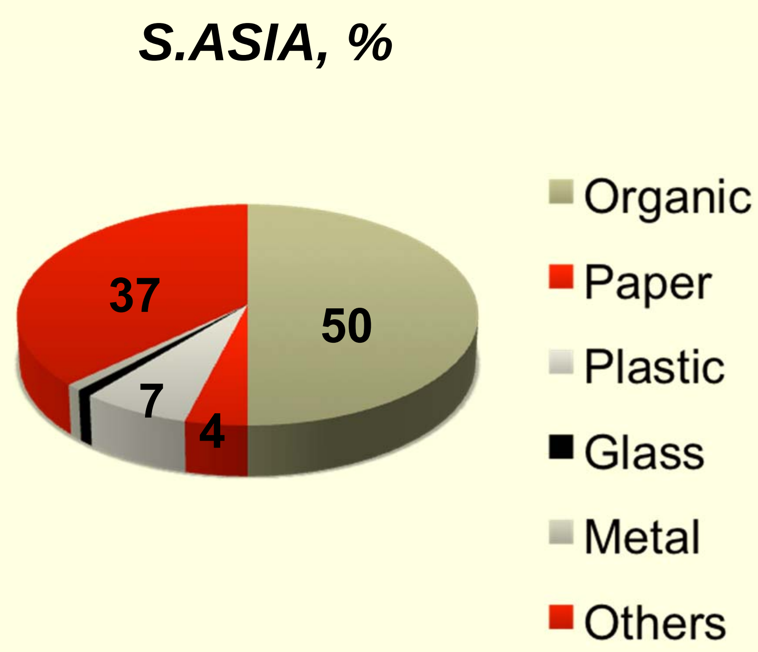


"The goods of today are the resources of tomorrow at yesterday's resource prices"

Professor Walter R. Stahel

WASTE COMPOSITION IS DIFFERENT IN DIFFERENT REGIONS OF THE WORLD





More than 50% of the world's population have no access to regular trash collection; Unregulated dump sites serve about 4 billion people and hold over 40 % of the world's waste

Source: What a Waste, The World Bank, 2012

URBANIZATION OF INDIA

- India’s urban population is growing at 6 % per annum against a population growth of 1.7 % per annum
- India is currently 30% urbanized; About 380 million people living in 8000 cities
- 53 Indian cities have a population of over 1 million
- Land to population ratio has decreased four fold since 1950; India’s cities are land starved
- Governance of Indian cities are challenged by multiple bodies overseeing the city governance, namely, municipality, state government and quasi state bodies with many overlapping functions and all not necessarily working in concert

Source :The Economic Survey, 2017, Chapter 14, Government of India

URBAN WASTE: THE INDIAN PROBLEM

- Urban India produces 70 mtpa of Municipal Solid Waste; of this 27 mtpa is sent to landfill and close to 15 mtpa is left to rot in the open
- MSW is likely to be about 165 mtpa by 2030 and 500 mtpa by 2050
- Delhi alone will need 28 sq km of land for landfill by 2020, an area of the size of Lutyen's Delhi !
- Plastic wastes in many urban area constitute about 10-15 % of the total MSW

City	MSW, tpd
Delhi	9000
Mumbai	6500
Bangalore	5000
Kolkata	4500
Chennai	4500
Ahmedabad	4200
Pune	2000

Land filling un-segregated waste is an environmental disaster; toxic leachates, ground water contamination, bacterial growth, methane generation and fire hazard


DEONAR
India's Largest Dumping Ground

CHALLENGES FOR BIO DERIVED POLYMERS

- Implications of contamination of compostable and bio degradable polymers with those which are generally recycled or landfilled
- Inadequate availability of industrial composting infrastructure
- Technology gaps in using waste agricultural residues as feedstocks for making polymers; all biopolymers today are derived from edible sugars
- Range of accessible properties; Polyesters are the only class of polymers that are compostability and biodegradable; no performance differentiator for bio polymers, except their biodegradability

CHALLENGES FOR BIO DERIVED POLYMERS

- Biomass is not fungible
- Transportation and storage of feedstocks; supply chain issues and integration
- Feedstocks quality variability; regional and geographic and climatic
- Engineering challenges : handling of high bulk density solids, corrosion and material of construction; drying and water recycling
- Process challenges : robust catalysts with long life time; catalyst fouling issues
- Separation science and technology

New paradigms in manufacturing : distributed manufacturing; part processing of feedstocks close to where it is produced; skid mounted mobile process plants

Decouple economics with scale : large single location biomass derived manufacturing inconceivable; risks too high

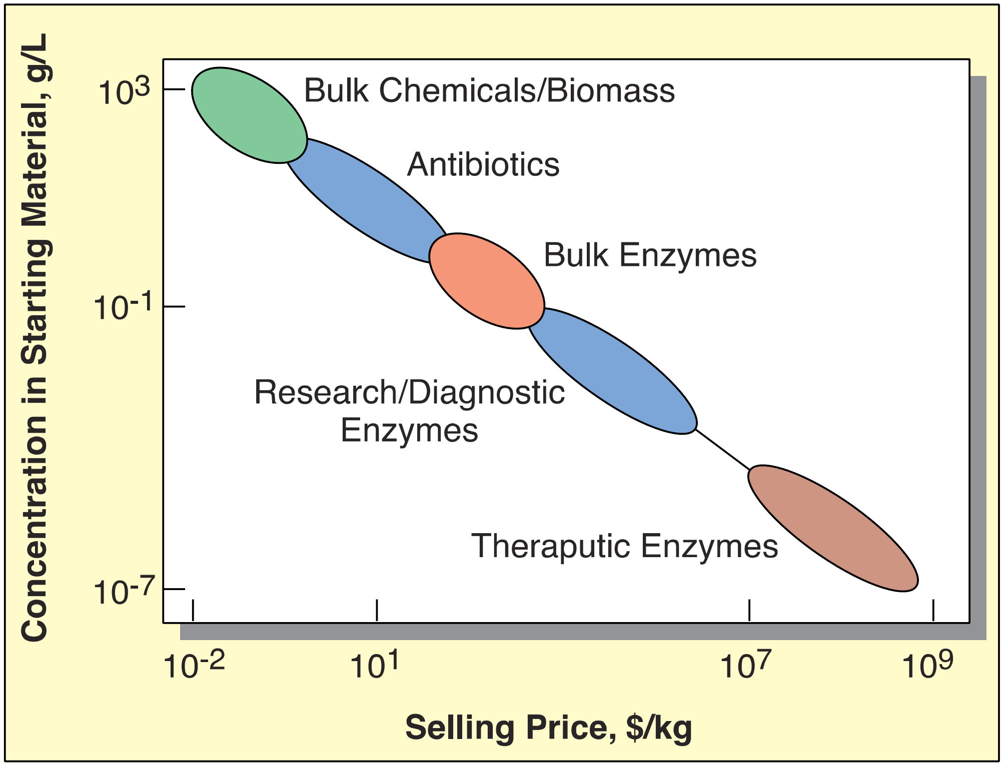


Figure 1. Economy of scale: correlation between achievable product concentration and selling price for common fermentation products.

PRODUCT RECOVERY AND PURIFICATION IS A LARGE PART OF A FERMENTATION PROCESS

Fermentation processes are not inexpensive !

Only around at 1000 g/L productivity, the production of bulk chemicals becomes viable; Such high productivities have yet not been achieved!

Table. Recovery or purification cost as a percentage of total production cost for typical fermentation products.

Source	Product	Recovery cost as of percentage of total production cost
Whole-cell yeast biomass	Single-cell-protein, yeast extract	5%
Bulk chemicals	Lactic, citric and malic acids	10–50%
Extracellular enzymes	Amylases, proteases	10%
Antibiotics	Penicillin	20–50%
Intracellular enzymes/proteins	Human insulin, interferon	90%

SOME SCIENCE AND TECHNOLOGY GAPS

- Polymers for packaging with single composition and the functionality of multilayer materials
- Polymers that can depolymerize cleanly into monomers (polymers with tailored ceiling temperatures)
- Adhesives that can be easily degraded by application of a trigger; bio-degradable and bio-compatible adhesives
- Design of products using only one type of polymer
- Polymers capable of degrading in marine and aqueous environments
- Food compatible markers for easy identification and sorting of plastics using hand held devices and white LED's (465-700 nm)
- Compostable polymers with a WVTR of < $8 g/m^2/day/atm$ and OTR of < $55 cm^3/m^2/day/atm$
- More environmentally benign and efficient waste to fuel technologies

GAS PERMEABILITY PROPERTIES OF PLA

Permeability	PLA
Oxygen, cc-mil/m^2.day.atm (ASTM D1434)	550
Carbon Dioxide, cc-mil/m^2.day.atm (ASTM D1434)	3,000
Water, g-mil/m^2.day.atm (ASTM E96)	325

- PLA 4030D, 4040D, 4041D Cargill Dow LLC, Published June 2000

PLA does not meet the requirement

Target : Oxygen < 55 cm^3 / m^2.day.atm; Water : < 8 g / m^2.day.atm

BIO-BASED / BIODEGRADABLE POLYMERS : SOME FACTS

- 250 companies,363 locations; highly fragmented and many of them yet to make even cash surplus !
- Niche products serving specializing markets
- 1 % of total polymer consumed
- US $ 1 billion in market value in a 1 trillion buisness
- Most plant capacities <5000 tpa. Exceptions, about 140,000 tpa PLLA by Nature Works Inc., 45,000 tpa 1,3-propanediol, DuPont – Tate & Lyle

KEY TO SUSTAINABLE PLASTICS INDUSTRY

- Promote responsible manufacturing and marketing
- Promote responsible consumption

Macromolecules 50 YEARS
Perspective
pubs.acs.org/Macromolecules

50th Anniversary Perspective: There Is a Great Future in Sustainable Polymers

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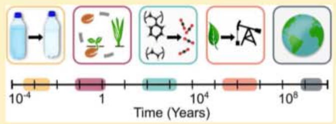
ABSTRACT: It is likely that a half-century ago even enthusiastic and optimistic proponents of the synthetic polymer industry (Mr. McGuire included) could not have predicted the massive scale on which synthetic polymers would be manufactured and used today. Ultimately, the future success of this industry will rely on the development of sustainable polymers—materials derived from renewable feedstocks that are safe in both production and use and that can be recycled or disposed of in ways that are environmentally innocuous. Meeting these criteria in an economical manner cannot be achieved without transformative basic research that is the hallmark of this journal. In this Perspective we highlight five research topics—the synthesis of renewable monomers and of degradable polymers, the development of chemical recycling strategies, new classes of reprocessable thermosets, and the design of advanced catalysts—that we believe will play a vital role in the development of sustainable polymers. We also offer our outlook on several outstanding challenges facing the polymer community in the broad area of sustainable polymers.



I. INTRODUCTION

To highlight the magnitude of an important challenge now facing polymer science, we begin this Perspective on sustainable polymers with a broad look at a seemingly unrelated topic, earth science. There is currently a rift in the field of geology. At the heart of the controversy is nomenclature, specifically whether or not the *Holocene*—the epoch which began almost 12 000 years ago at the end of the last glacial period and which encompasses all written human history—has now ended.[1,2] Although a host of climatic, atmospheric, biological, and geochemical data support the idea that we are now living in a new geological epoch, the *Anthropocene*,[3,4] some earth scientists contend that there is not enough evidence in the rock record to make this designation.[5] In 2016, a process to formalize the *Anthropocene* was launched within the International Commission of Stratigraphy (ICS). This process begins with identifying a primary signal to serve as a marker of this new epoch in the rock record. Among those currently favored are plutonium fallout and radiocarbon spikes from atomic bomb tests, increases in carbon dioxide concentration from burning fossil fuels, and, most relevant to our discussion, plastic.[6,a] The history of the synthetic polymer industry, from the localized introduction of Bakelite and Rayon in urban centers during the early 20th century to the global proliferation of commodity plastics following the Second World War, will be recorded in the sediment for centuries regardless of the specific marker chosen by the ICS.

Over the past 50 years, the uses for and production of synthetic polymers have increased exponentially. This is in large part due to the undeniable fact that these materials provide many societal benefits including those strongly and positively connected to sustainability (e.g., lightweight transportation to reduce fuel consumption, membranes for efficient water purification, and food packaging to prevent spoilage). However, polymer prices often do not reflect the true costs associated with their manufacture and disposal.[7] One major issue many synthetic polymers share is that they are derived from nonrenewable resources. Today a small but non-negligible percentage of the total oil produced annually (∼8%) is consumed for the manufacture of polymers, with the amount being used *directly* as the carbon source for the synthesis of monomers roughly equal to the quantity consumed *indirectly* for production processes.[8] This number is increasing monotonically; some argue that by 2050 the plastics industry alone will account for almost 20% of the total oil consumed annually.[8] The large scale on which synthetic polymers are produced can be concerning from an energy security and from an economic standpoint for the simple reason that petroleum consumed in their production (and their embedded energy content) is generally not recovered. As a specific example, currently over 40% of the ∼80 million tons of plastic packaging used every year is discarded in landfills with an astonishing 32% escaping the collection system or being dumped illegally.[9]

Aside from the considerable economic losses that result from the disposal of polymeric materials after a single use (estimated at ∼100 billion dollars annually for packaging materials alone), there are also the direct costs of disposal and the indirect, and often difficult to quantify, environmental costs of polymer pollution.[7,9] Synthetic polymers make up ∼11% of the total municipal solid waste (MSW) stream by mass; however, they take up a disproportionate volume in landfills due to their low density.[10] Unlike many other forms of trash, most synthetic

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SOME KEY ISSUES

- At what stage of the product discovery and development process should sustainability metrics be invoked ?
- Should the cost and abundance of a given feedstock, precursor or monomer be a consideration prior to undertaking a study?
- In the short term, what can we do to enhance the sustainability of currently used polymers

D.K.Schneiderman and M.A.Hilmyer, Macromolecules, 10.1021/acs macromol.7b00293, 2017

WHAT DOES THE CONSUMER NEED?

- Is the product I am using “safe” for me ?
- Is the product I am using made with the “lowest impact” on the resources of the planet ?
- What will happen to this product after my “use”? Where will it end up finally ?

Unfortunately, the plethora of sustainability metrics fail to address the above three simple concerns of the consumer clearly and unequivocally;
We badly need a simple and honest communication strategy

TEN MYTHS ON BIO-BASED POLYMERS

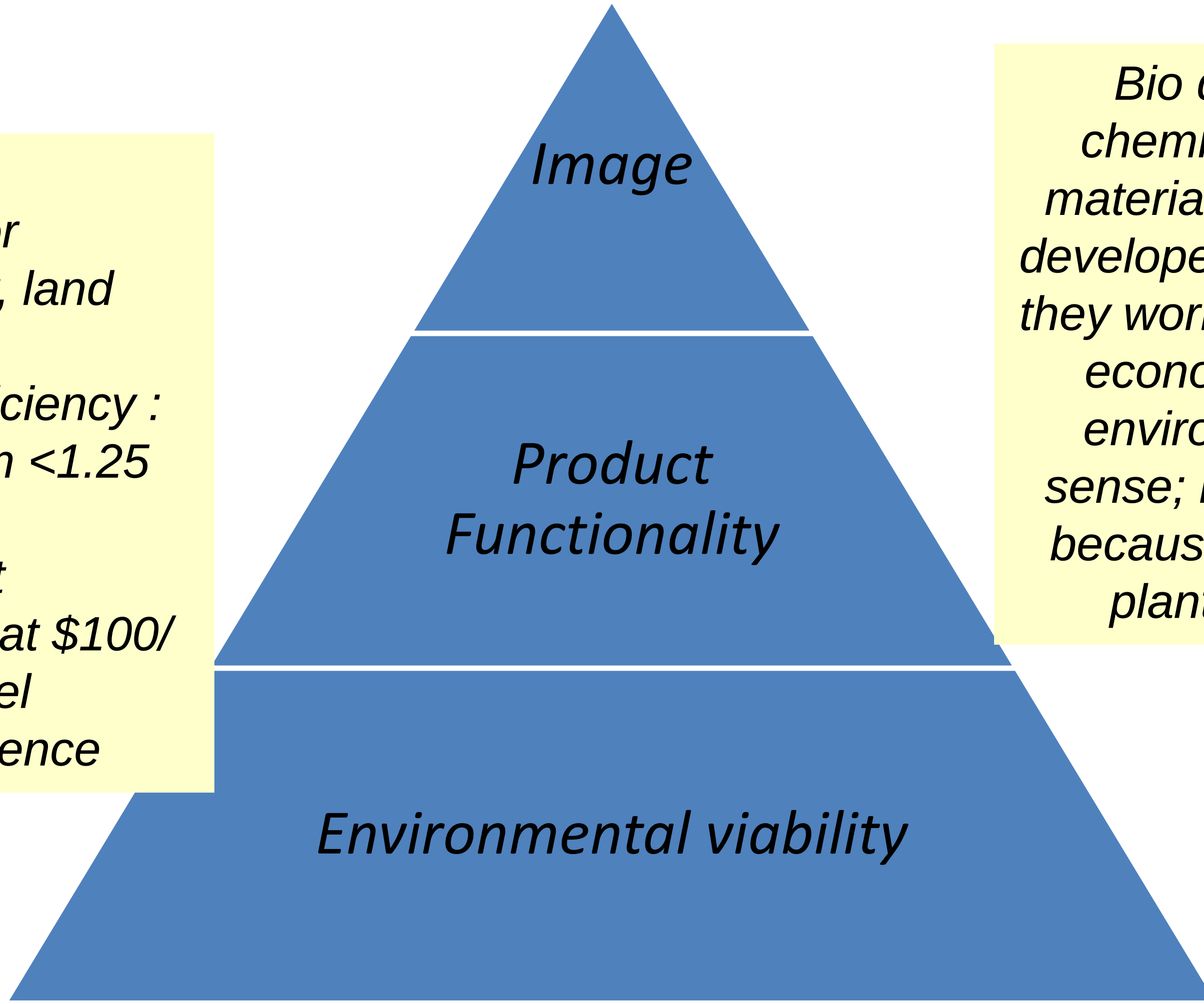
- Bio-based polymers are needed because fossil hydrocarbon is getting scarcer/expensive
- Bio-based polymers are green
- Bio-based polymers are environmentally degradable
- Bio-based polymers are inexpensive compared to hydrocarbon derived polymers
- Bio-based polymers can replace almost all polymers currently used for packaging applications

TEN MYTHS OF BIO BASED POLYMERS

- Bio-based and hydrocarbon-based polymers can coexist
- Bio-based polymers are intrinsically safer
- Bio-based polymers and chemicals makes good business sense
- Customer will pay any price if the polymer is derived from renewable feed-stocks
- Bio-based polymers will address all issues of sustainability of polymers and will wipe out the negative perception about plastics in the minds of consumers

THE BIOVALUE PYRAMID

- CO_2 Neutral
- Competition for resources (water, land and food)
- Conversion eficiency : 1 kg product from <1.25 kg of sugar
- Operating cost competitiveness at $100/ barrel of fossil fuel
- Capex equivalence



Bio derived chemicals and materials must be developed because they work and make economic and environmental sense; not merely because they are plant based

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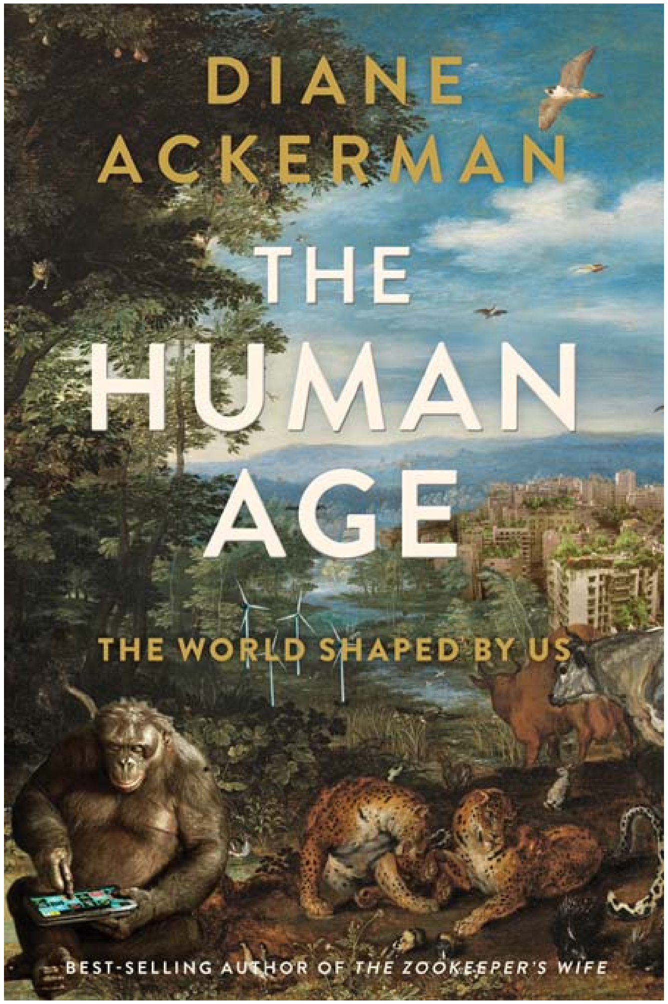
SUMMARY

- Creation of sustainable and environmentally friendly polymers for diverse applications and capable of substituting what we currently use appears to be a formidable challenge.
- There are no easy answers
- We need to focus on, both consumption as well as end of use disposal of short life cycle materials
- Who will drive this change? consumers, industry, Governments, NGO's and green Crusaders ?
- Can industry drive the change ? For this to happen industry have to become more honest and transparent

Can men who row the boat , rock it ?

THE HUMAN ANTHROPOCENE AGE

- Humans are leaving an indelible imprint on Planet Earth
  - Carbon cycle
  - Nitrogen cycle
  - Ocean pH
  - Extinction rate of species and habitats
- Human ingenuity and innovation capacity is also at an all time high
- However, emergence of technology alone is no guarantee that its benefit will tickle down to humanity at large.



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Our relationship with nature has changed radically, irreversibly, but by no means all for the bad. Our new epoch is laced with invention. Our mistakes are legion, but our talent is immeasurable."

Diane Ackerman,
The Human Age

However, we cannot afford to make more mistakes; the society will not forgive us , if we do


targets
zero-waste
cascade-circles
action-plan
research
renewable-materials
eco-innovation
knowledge
eco-design
LCA
renewable-energy
EMAS
multiple-circles
production-processes
products
inner-circles
ISO


SUSTAINABILITY
AHEAD

THANK YOU