Topic for Essay 1

- Introduce one material you are familiar with.
- Explain how this material has changed our life.
- Are there any environmental problems associated with this material? If so, how to solve the problems?

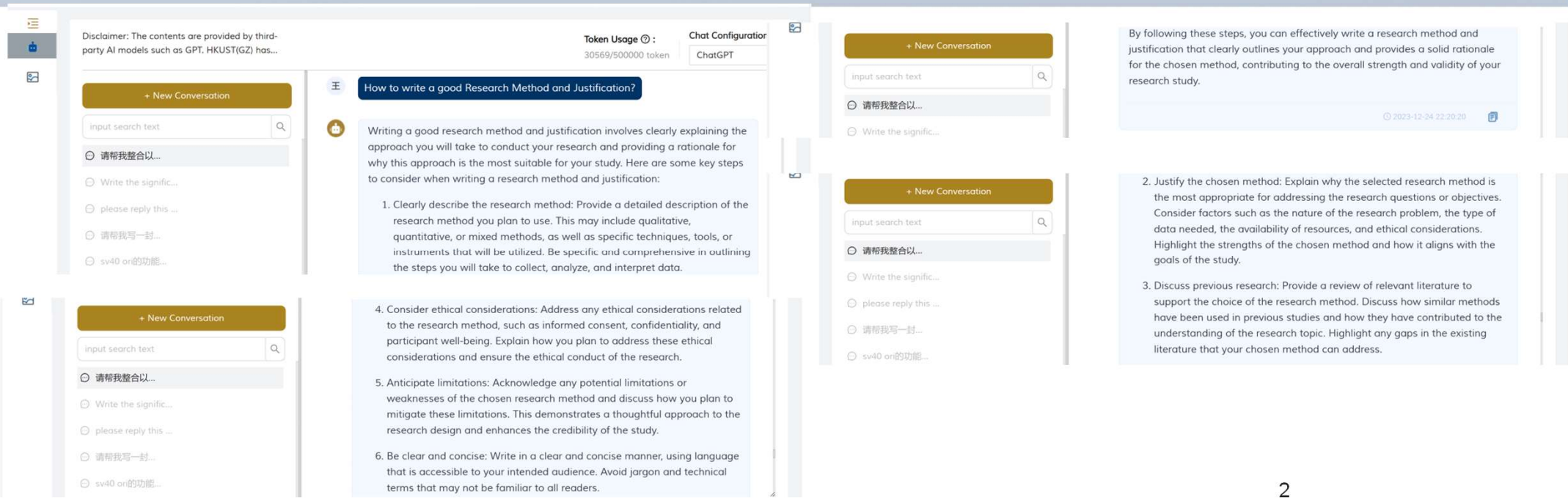
Requirements

- >=750 words
- No cheating allowed
- Statement of AI use
- Deadline is Sep 29th, 23:59pm

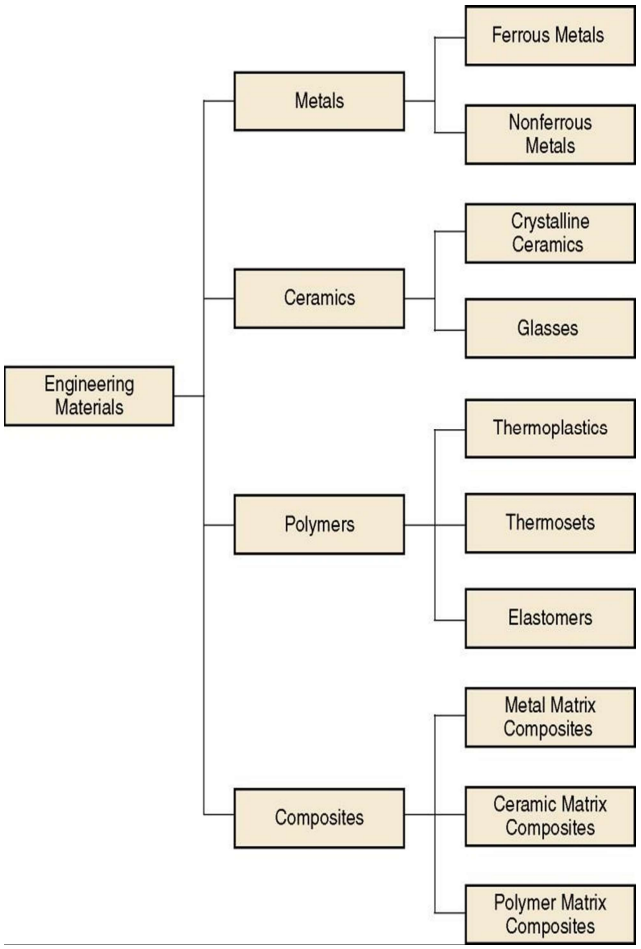
Rubric

	4-5 Points	2-3 Points	0-1 Point
Focus	Focuses on all points in the given topic	Basically focuses on the given topic, with some deviation	Not relevant to the given topic
Development	Specific, concrete, relevant information to support arguments	Uses support, but it maybe insufficient	Lacks sufficient details
Style	Excellent language use; precise wording	Adequate use of language	Vague and abstract
Length	>=750 words	400-750 words	<400 words
Statement on AI use, when AI is used	Comprehensive, detailed information	Including some examples	Lacks sufficient details

Example of statement on AI use



Materials and civilization



M.P. Groover, 5th edition, John Wiley & Sons Inc. (2007).

Stone Age

Pottery Age

Bronze Age

Iron Age

Steel Age

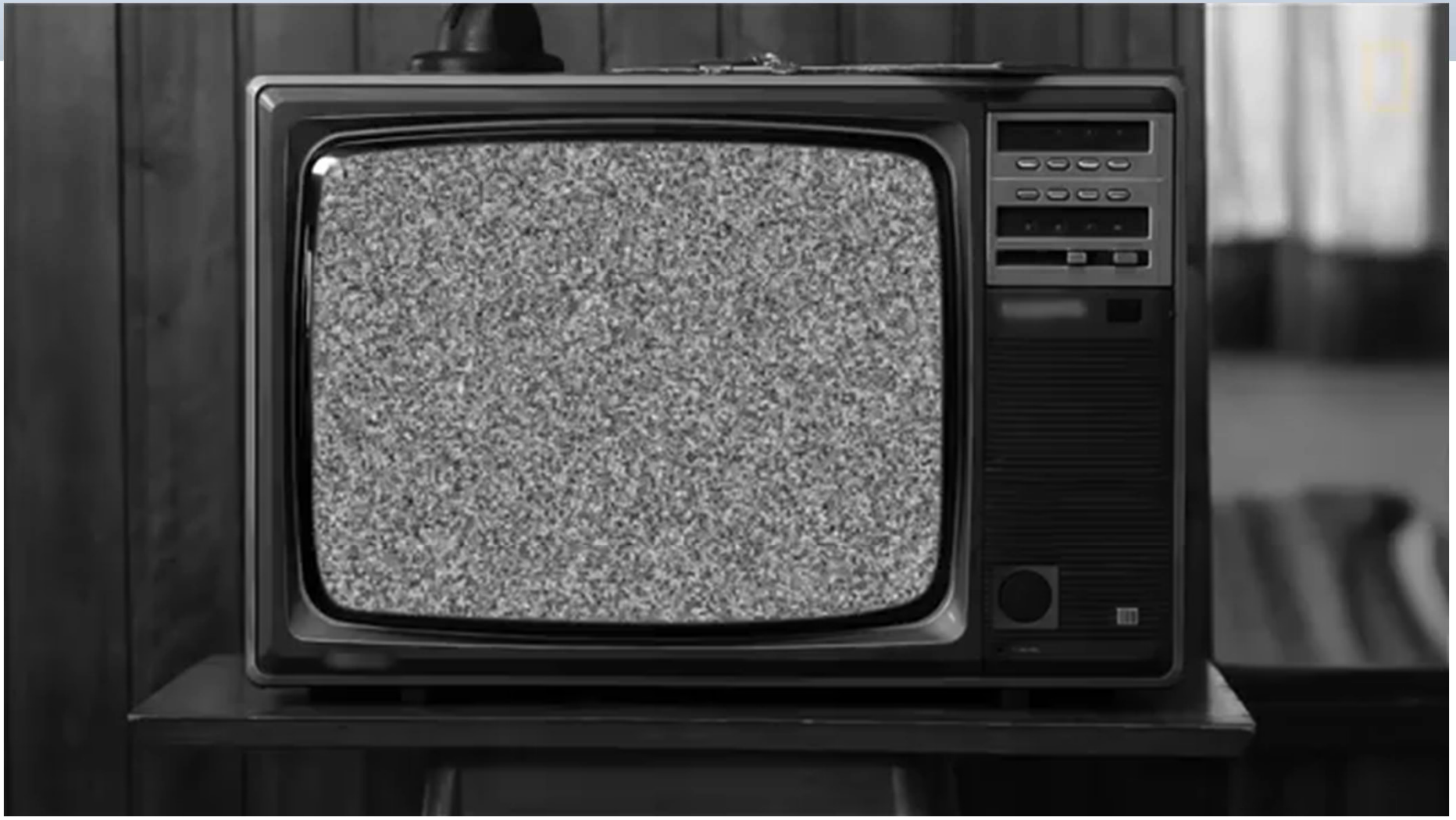
Polymer Age

Silicon Age

……

- **The evolution of materials is incremental and continuous, driven by the needs of human beings.**
- **New materials are revolutionary and have shaped the development of civilization**
- **More advanced civilization is often characterized by using more advanced and sophisticated materials.**

The story of plastics



Quiz 1

Polymer_vote_section 1

* 1. Which of the following materials are polymer?【多选题】

- [ ] Cotton
- [ ] Glass
- [ ] Protein
- [ ] Plastics
- [ ] Steel

提交

Introduction to Function Hub For Sustainable Future

Lecture 2： Polymers

Qichun Yang

2024-9-12

香港科技大学(广州)
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

Vocabulary of this lecture

- **Polymer:** 聚合物
- **Covalent Bond:** 共价键
- **Molecule/Molecular:** 分子/分子的
- **Macromolecule:** 大分子
- **Atom:** 原子
- **Catalyst:** 催化剂
- **Ethylene:** 乙烯
- **Acetylene:** 乙炔
- **Flammable:** 易燃的
- **Biodegradable:** 可生物降解的
- **Thermoplastic:** 热塑性
- **Thermosetting:** 热固性
- **Resin:** 树脂
- **Viscosity:** 黏度
- **Ductile：** 延展性
- **Amorphous:** 非晶体的

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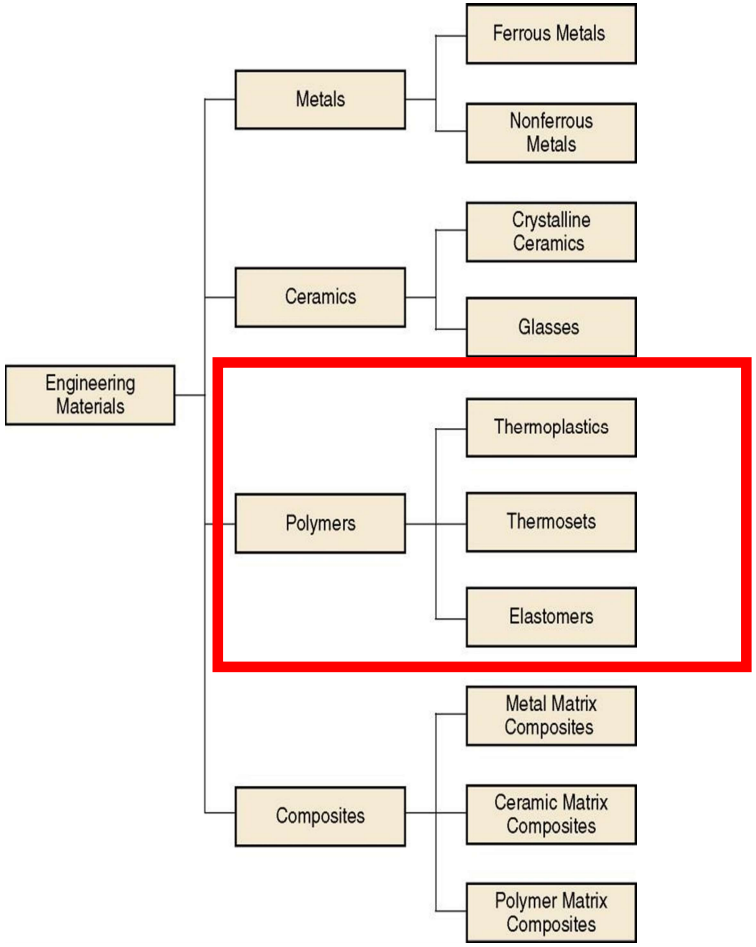
Polymer and civilizations



M.P. Groover, 5th edition, John Wiley & Sons Inc. (2007).

Stone Age
↓
Pottery Age
↓
Bronze Age
↓
Iron Age
↓
Steel Age
↓
Polymer Age
↓
Silicon Age

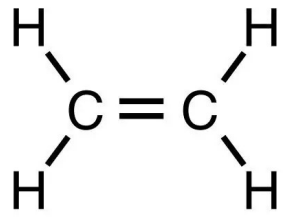
……

Development of Polymer

- **Monomer**: a molecule of any compounds
- **Poly**: many
- **-mer** : parts
- **Polymer**: many parts
- Polymer vs. **monomer**

  Molecular weight

  Property

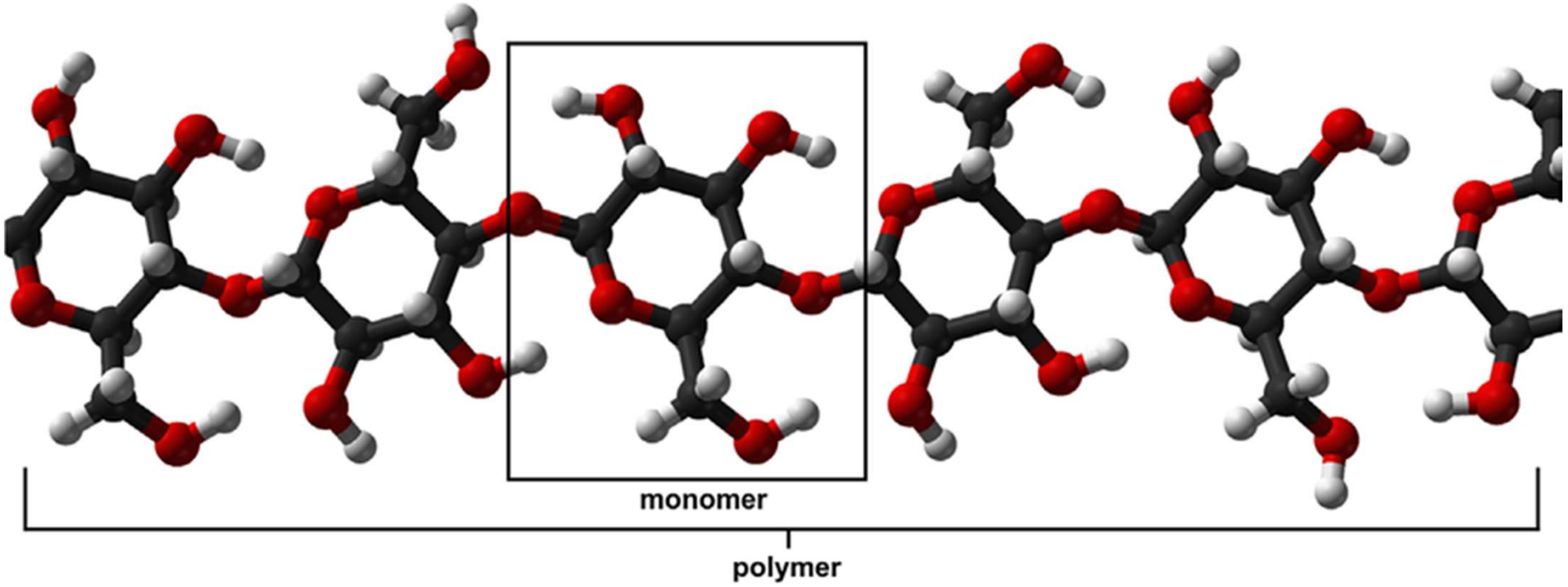


ethylene

$$nCH_2{=}CH_2 \rightarrow -[CH_2{-}CH_2]-_n$$

Polyethylene

Development of Polymer



Arumugam， et al., 2016

Different Types Polymer

- **Natural Polymers**
  Occur naturally and are found in plants and animals： Cotton, silk, starch

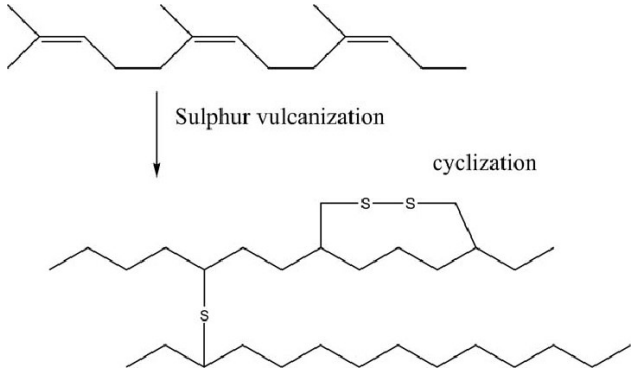
- **Semi-synthetic Polymers**
  Derived from naturally occurring polymers and undergo further chemical modification: cellulose nitrate.

- **Synthetic Polymers**
  Human-made polymers. **Plastic** is the most common and widely used synthetic polymer.

https://byjus.com/， https://www.hawach.com/，
https://www.plasticsengineering.org/

Development of Synthetic Polymers

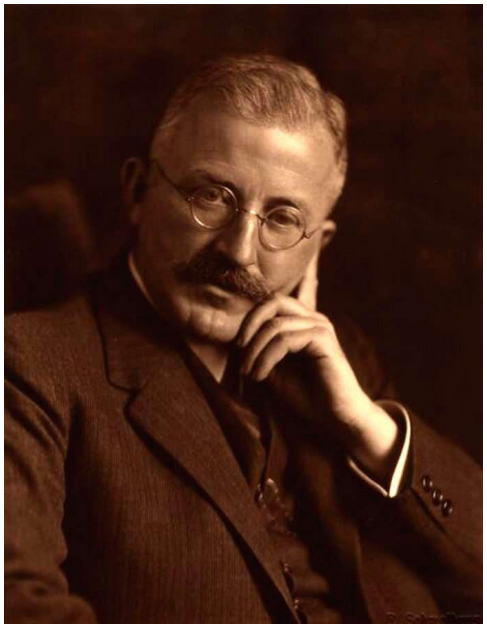
- **1850s: Rubber vulcanization**



- **1907: The birth of synthetic polymer industry - phenol formaldehyde (酚醛树脂)**

Development of Synthetic Polymers

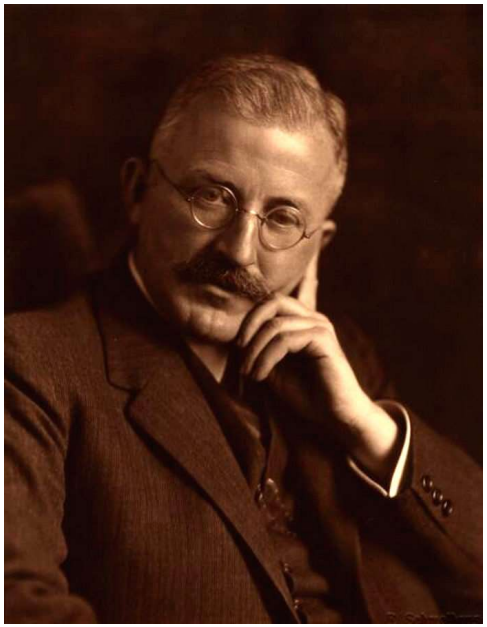
- **Demonstrate the existence of macromolecule**
- **1920: Über Polymerisation, explained that protein, starch, rubber have long chains of short repeating molecules linked by covalent bonds**
- **Winner of the Nobel Prize in 1953**



Hermann Staudinger

Development of Synthetic Polymers

Heinrich Wieland (1927 Nobel Prize in Chemistry) wrote to Staudinger, “Dear Colleague, drop the idea of large molecules; organic molecules with molecular weight higher than 5000 do not exist. Purify your products, such as rubber, then they will crystallize and prove to be low molecular compounds.”



Hermann Staudinger

Development of Synthetic Polymers

- A pioneer in understanding the behavior of polymers in solution.
- Introduced the concept of excluded volume, explaining the ending of polymer chains in solutions
- Developed an original method for computing the probable size of a polymer in good solution
- Author of 'Principles of Polymer Chemistry'

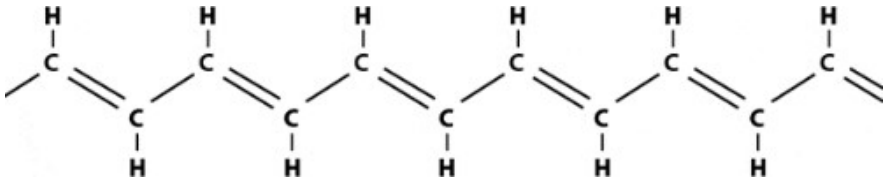
  Bible of Polymer Science
- Winner of the Nobel Prize in 1974

Paul J Flory

Year	Polymer	Producer
1909	Poly(phenol–*co*–formaldehyde)	General Bakelite Corporation
1927	Poly(vinyl chloride)	B.F. Goodrich
1929	Poly(styrene–*stat*–butadiene)	I.G. Farben
1930	Polystyrene	I.G. Farben/Dow
1936	Poly(methyl methacrylate)	Rohm and Haas
1936	Nylon 66 (Polyamide 66)	DuPont
1936	Neoprene (chloroprene)	DuPont
1939	Polyethylene	ICI
1943	Poly(dimethylsiloxane)	Dow Corning
1954	Poly(ethylene terephthalate)	ICI
1960	Poly(*p*-phenylene terephthalamide)[a]	DuPont
1982	Polyetherimide	GEC

Development of Synthetic Polymers

- Nobel Prize in Chemistry 2000 was awarded to lan J. Heeger, Alan G. MacDiarmid and Hideki Shirakawa.
- For the finding of conductive polymers



Polyacetylene

- Demonstrate properties like metal in conducting electricity
- LED for lighting, color screen for video, electronic chips

https://www.nobelprize.org/

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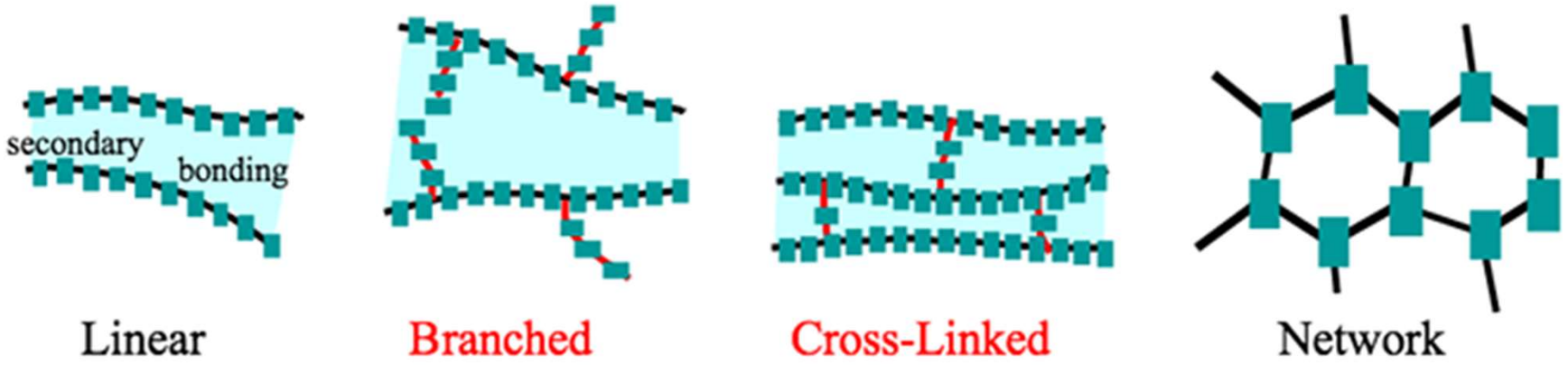
Polymer molecule structure

- Molecule structure

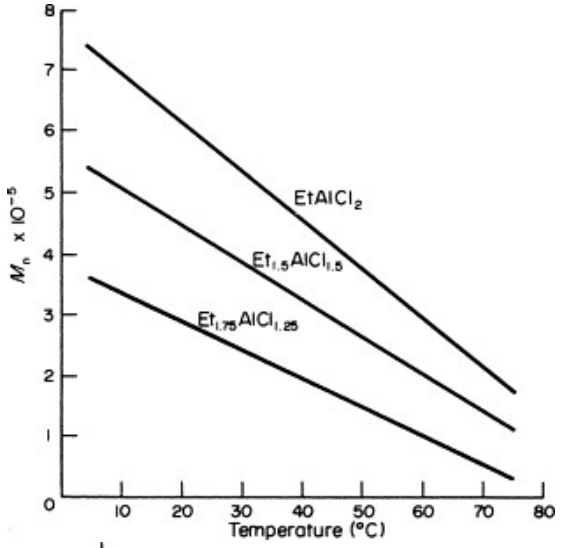


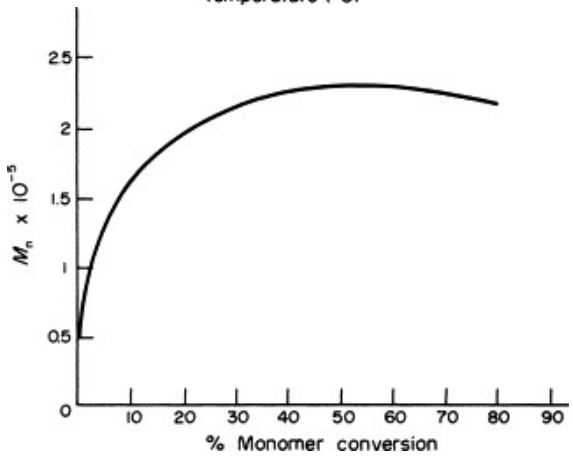
- Linear: thermoplastic, easy to be remolded, **polyethylene**
- Branched: thermoplastic，**polypropylene**
- Cross-linked: tied together via covalent bonding，thermosetting, **rubber**
- Network: three-dimensional linkages, thermosetting, **phenol-formaldehyde**

https://www.e-education.psu.edu/

Polymer Molecular Weight

- Polymer Molecular Weight refers to the sum of the atomic weights of individual atoms in a polymer molecule
- A fundamental property of polymers
- Molecular weight determined multiple factors such as solvent, monomer concentration, polymerization temperature, and monomer conversion.

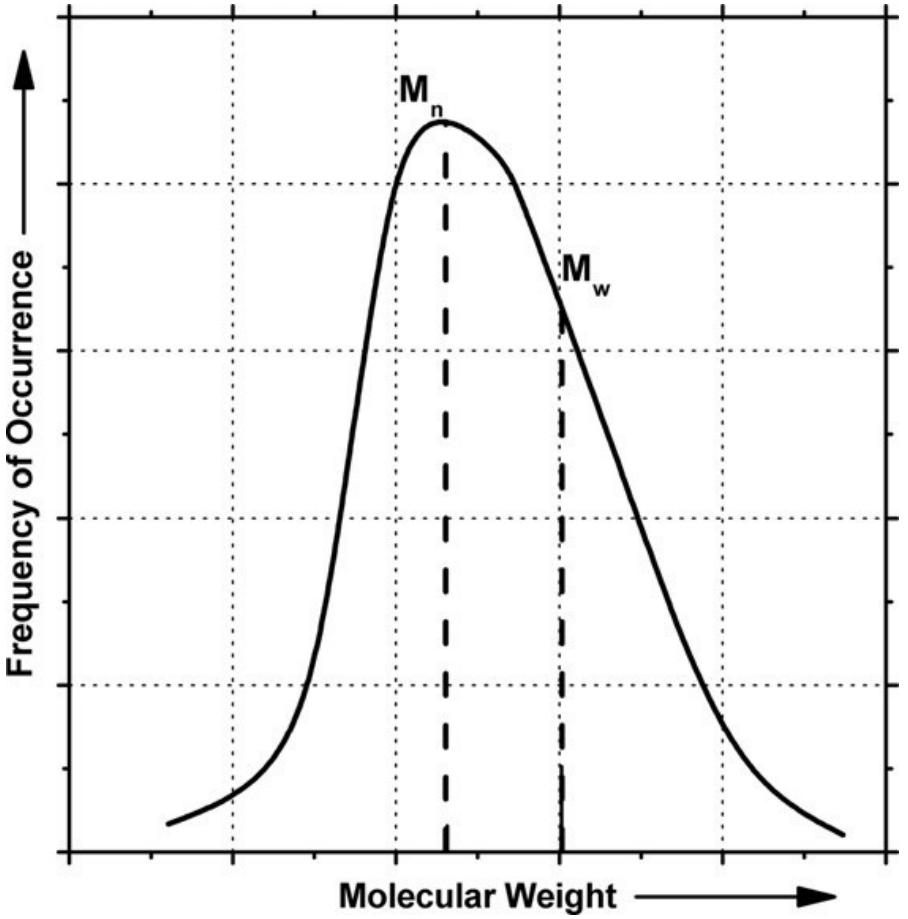




Lido Porri, Antonino Giarrusso, 1989

Polymer Molecular Weight

- All polymer molecules of a particular grade do not all have the exact same molecular weight.
- Same polymer from different sources may have different weight.
- How to measure molecular weight?
  - ✓ Light scattering
  - ✓ Ultracentrifugation



http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Polymer Molecular Weight

- Number-average weight M_n

$$M_n = \frac{\sum_i N_i M_i}{\sum_i N_i}$$

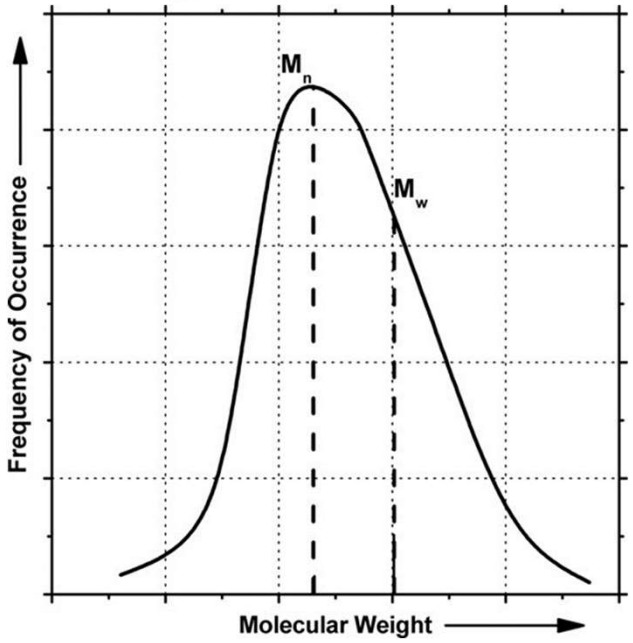
- Weight-average weight M_w

$$M_w = \frac{\sum_i N_i M_i^2}{\sum_i N_i M_i}$$

where:

i is the number of polymer molecules

N_i is the number of molecules that have the molecular weight M_i.



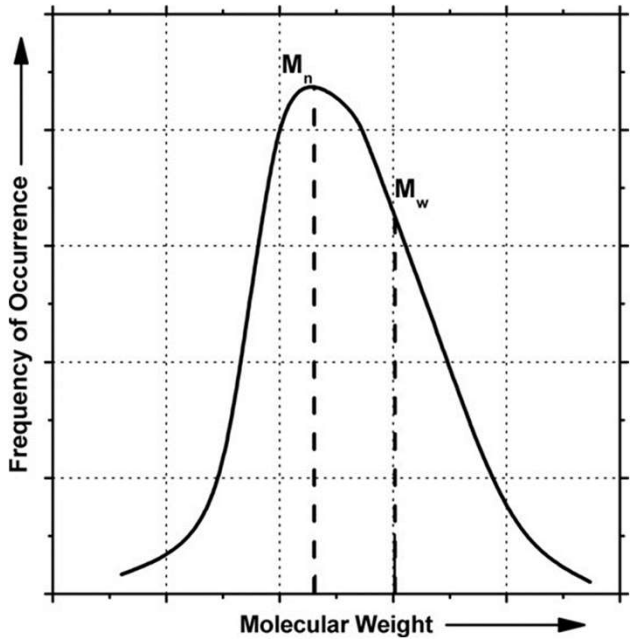
http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Polymer Molecular Weight

- Molar-mass dispersity index (*Poly-dispersity*), or PDI

$$\text{PDI} = \frac{M_w}{M_n}$$

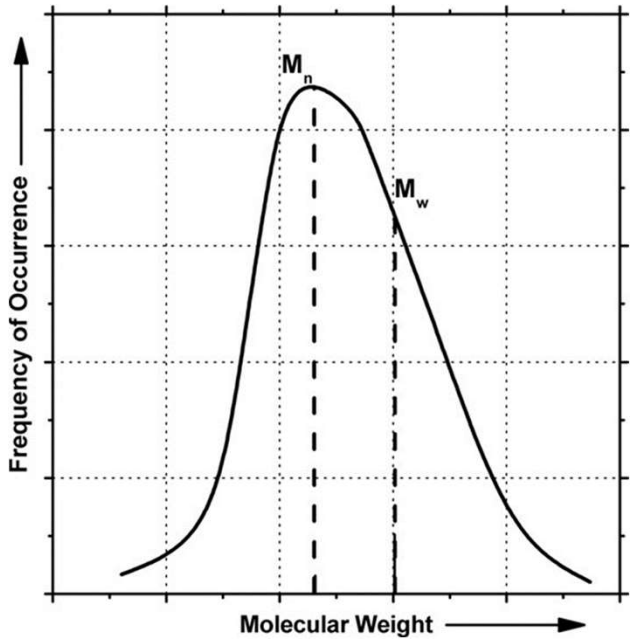
- PDI is unitless, should be 1 when Molecular weight is evenly distributed.



http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Polymer Molecular Weight

- Narrow distribution often means better properties
- Lower end acts as plasticizer, softening material
- Higher end contribute to the processing difficulties, because higher weight indicates higher viscosity



http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Polymer Molecular Weight

- Molecular weight affects the Permeation property.
- Permeation decrease with molecular weight.
- Larger dispersity means larger amount of low-weight molecules, suggesting higher permeation rates.

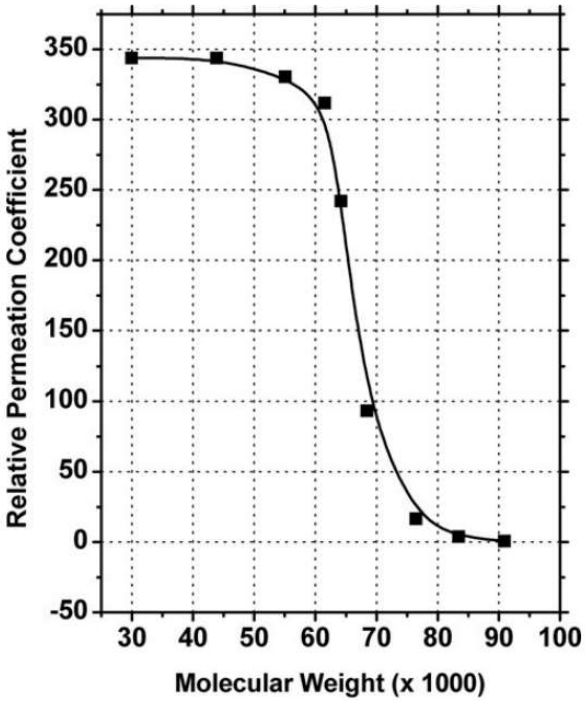


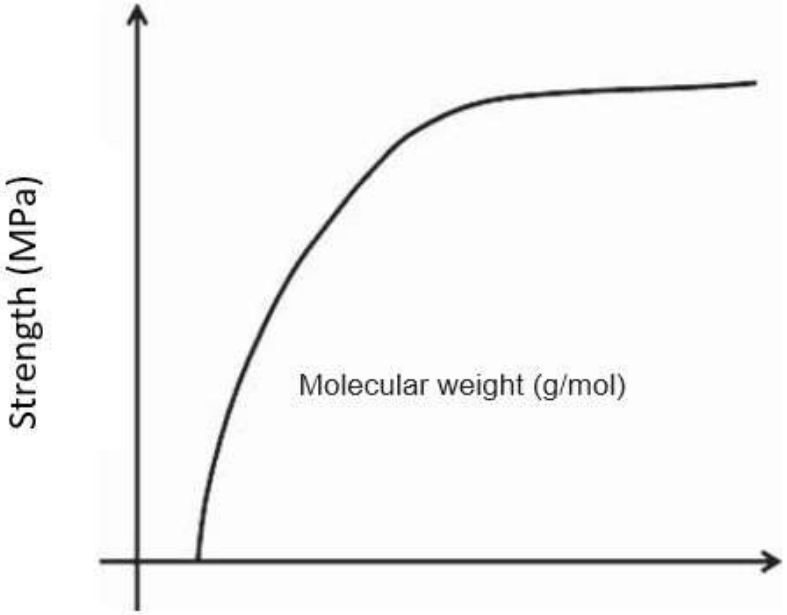
Figure 2.15 Water permeation of ethylene–vinyl alcohol copolymer vs. polymer molecular weight.[6]

http://dx.doi.org/10.1016/B978-1-4557-2598-4.00002-2

Polymer Molecular Weight

- Tensile strength (σ): the stress at break during elongation
- For polymer with low molecular weight, the tensile strength tends to be zero
- Tensile strength increases with molecular weight

$$\sigma = \sigma_{\infty} - \frac{A}{M}$$



https://textilestudycenter.com/mechanical-properties-of-polymers/

Molecular weight and property

Number of Carbons in Chain	State and Properties of Material	Applications
1–4	Simple gas	Bottled gas for cooking
5–11	Simple liquid	Gasoline
9–16	Medium-viscosity liquid	Kerosene
16–25	High-viscosity liquid	Oil and grease
25–50	Crystalline solid	Paraffin wax candles
50–1000	Semicrystalline solid	Milk carton adhesives and coatings
1000–5000	Tough plastic solid	Polyethylene bottles and containers
$3–6 \times 10^5$	Fibers	Surgical gloves, bullet-proof vests

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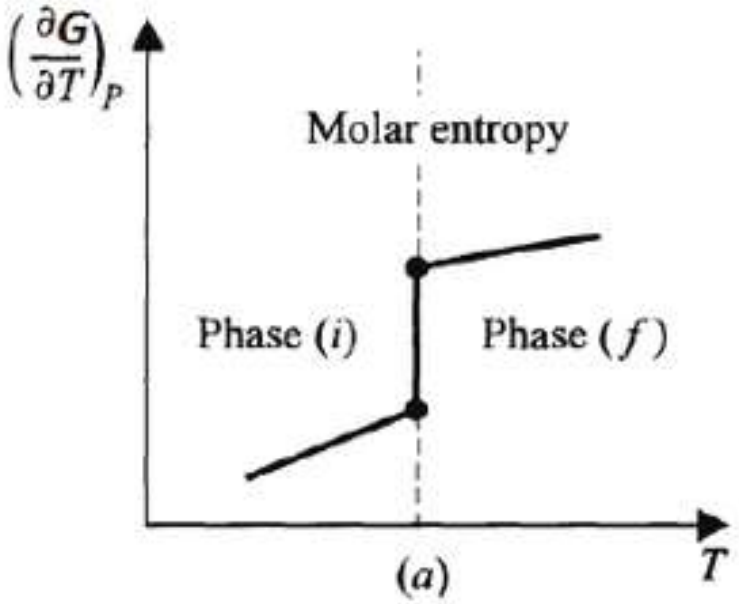
Thermal Properties of Polymers

- Melting point
  - ✓ From solid to liquid
  - ✓ First order transition
  - ✓ Discontinuous
  - ✓ Specific to material with crystal structure



Wasif and Anward 2016

Thermal Properties of Polymers

For amorphous or semi-crystalline polymers

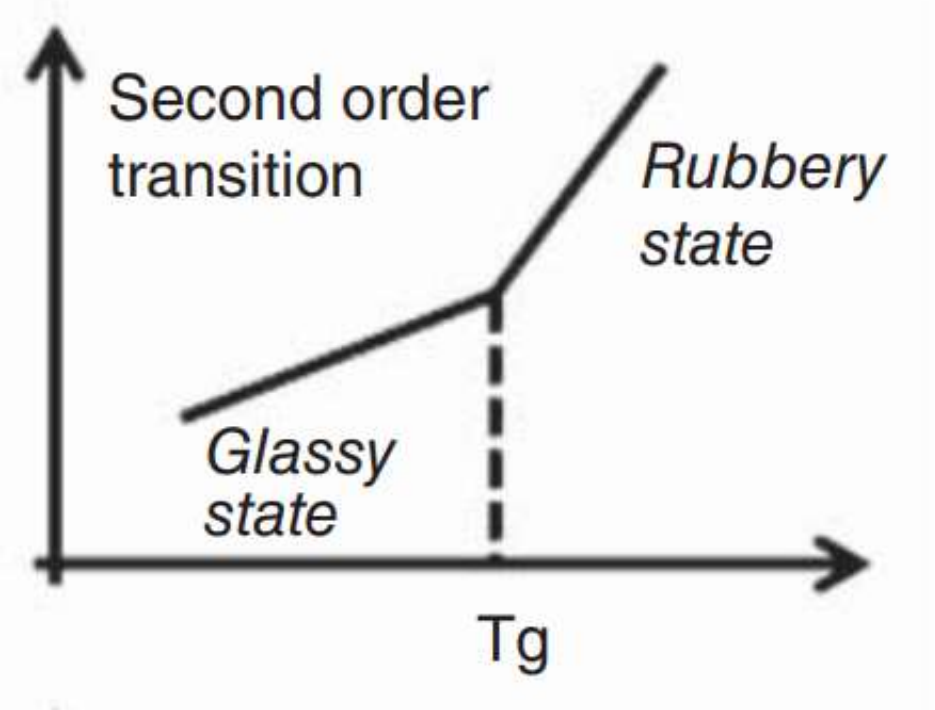
- Glassy state
  - ✓ Frozen state
  - ✓ Polymer is brittle and hard
  - ✓ Like glass

- Rubbery state
  - ✓ Polymer chain wiggles around
  - ✓ Polymer becomes soft

plasticexpert.com, https://www.plasticsengineering.org/

Thermal Properties of Polymers

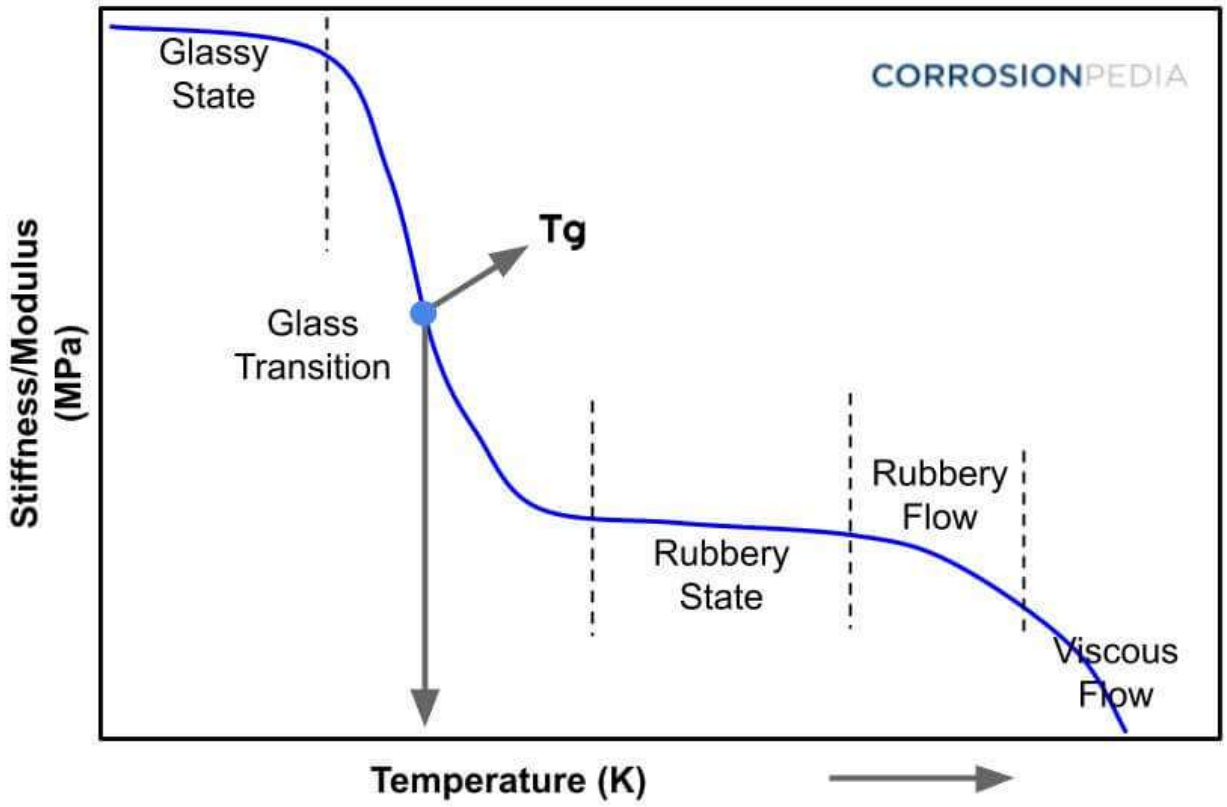
- Glass-rubber transition
  - ✓ Tg: transition temperature between the glassy and rubbery states
  - ✓ Continuous
  - ✓ Second order transition



Biosurfaces: A Materials Science and Engineering Perspective, First Edition

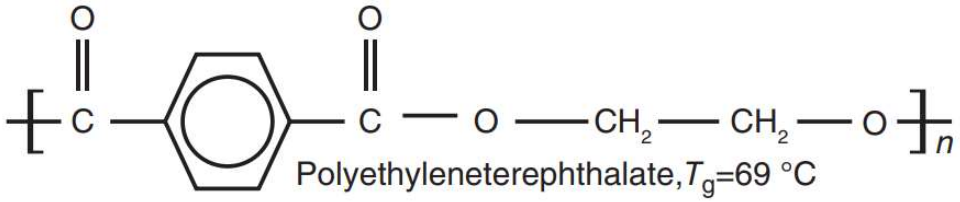
Thermal Properties of Polymers

- Glassy state
- Glass transition
- Rubbery State
- Rubbery flow
- Viscous flow



https://www.corrosionpedia.com/

Thermal Properties of Polymers



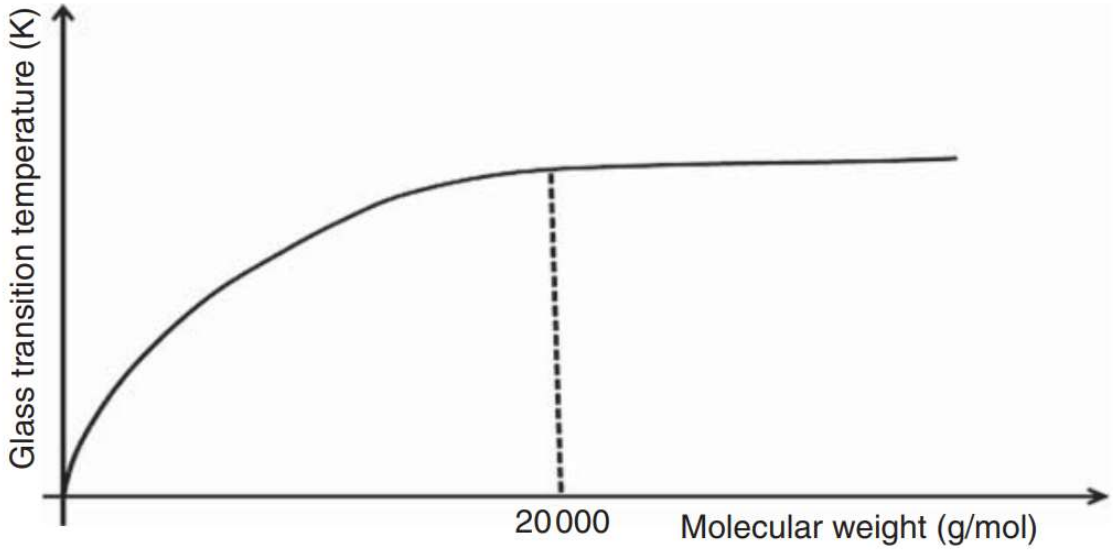
Polyethyleneterephthalate, T_g=69 °C

Region	Polymer	Application
Glassy	Poly(methyl methacrylate)	Plastic
Glass transition	Poly(vinyl acetate)	Latex paint
Rubbery plateau	*Cross*-poly(butadiene–*stat*–styrene)	Rubber bands
Rubbery flow	Chicle[a]	Chewing gum
Viscous flow	Poly(dimethylsiloxane)	Lubricant

Biosurfaces: A Materials Science and Engineering Perspective, First Edition

Factors affecting Tg

- Intermolecular forces
- Complexity of molecular chains structures: stiffness, cross-linking
- Plasticizers
- Molecular Weight



$$T_g = T_{g,\infty} - \frac{K}{M_n} \qquad \text{(Fox–Flory Equation)}$$

Biosurfaces: A Materials Science and Engineering Perspective, First Edition

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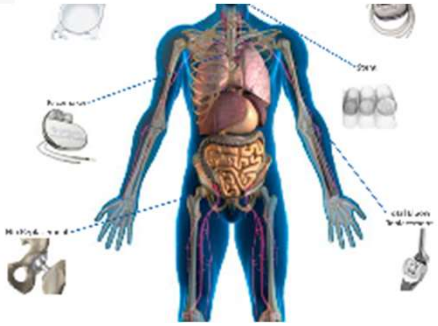
Use of Plastics

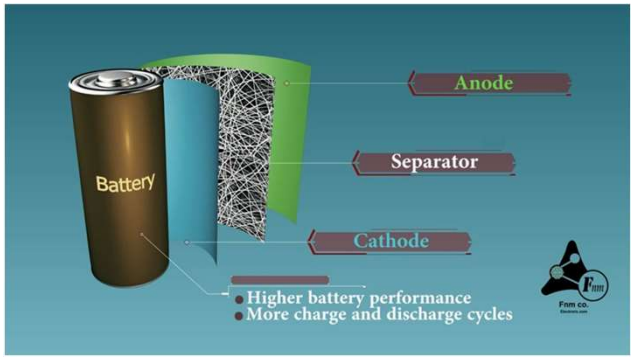
- Soft, ductile, low strength, low density
- Low cost
- Thermal & electrical insulators
- Optically translucent or transparent.
- Chemically inert and unreactive, resistant to corrosion

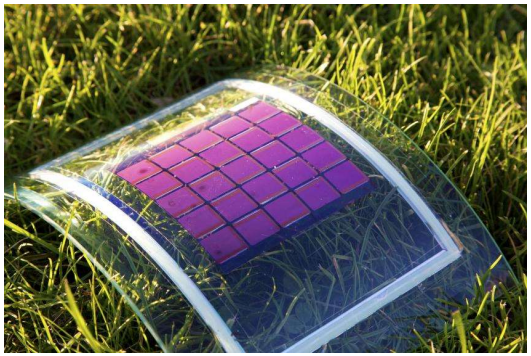
https://www.undp.org/

Use of Plastics

- 3D printing
- Electronics
- Medical implants
- Battery
- Renewable energy
- …..







Credit to Prof. Gao

Advanced Plastics

Important Research Areas of Polymer Science

- Optical polymer thin films for smart and flexible displays.
- Biomedical polymer thin films for implantable/wearables.
- Environmental thin films (eg. Desalination membranes; Ultrafiltration in Microelectronic Fabrication)
- Energy thin films (eg., Battery separators, fuel cell separators, flow batteries, solar cells, etc.)

Credit to Prof. Gao

近日，香港科技大学（广州）先进材料学域学生团队参与创立的PointFit Technology Limited（以下简称"PointFit"）的项目"**用于预防性诊断的皮肤贴片汗液传感器**"（Skin Patch Sweat Sensor for Precautionary Diagnostics）摘得"2024创业世界杯（SWC）中国区总决赛"冠军，团队将于10月赴美国旧金山参加全球总决赛，与超过50个国家和地区的团队角逐。

**赛事说明详见文末*

今年，港科大（广州）的录取通知书中有一张夺目的金色薄膜，仅有头发丝1/300的厚度，却有超过不锈钢25倍的比强度，同时防水、透气、贴合肌肤。

Table of content

Limitations of Plastics

- Non-biodegradable
  400-1000 years to decompose
- Many are flammable
- Toxic
- Causing pollution in the production and recycling processes

https://www.cuspuk.com/fire-safety

Plastic Pollution

> 80% waste!

1. X. Zhao et al, Adv. Mater. 2100843 (2021)

Plastic Pollution

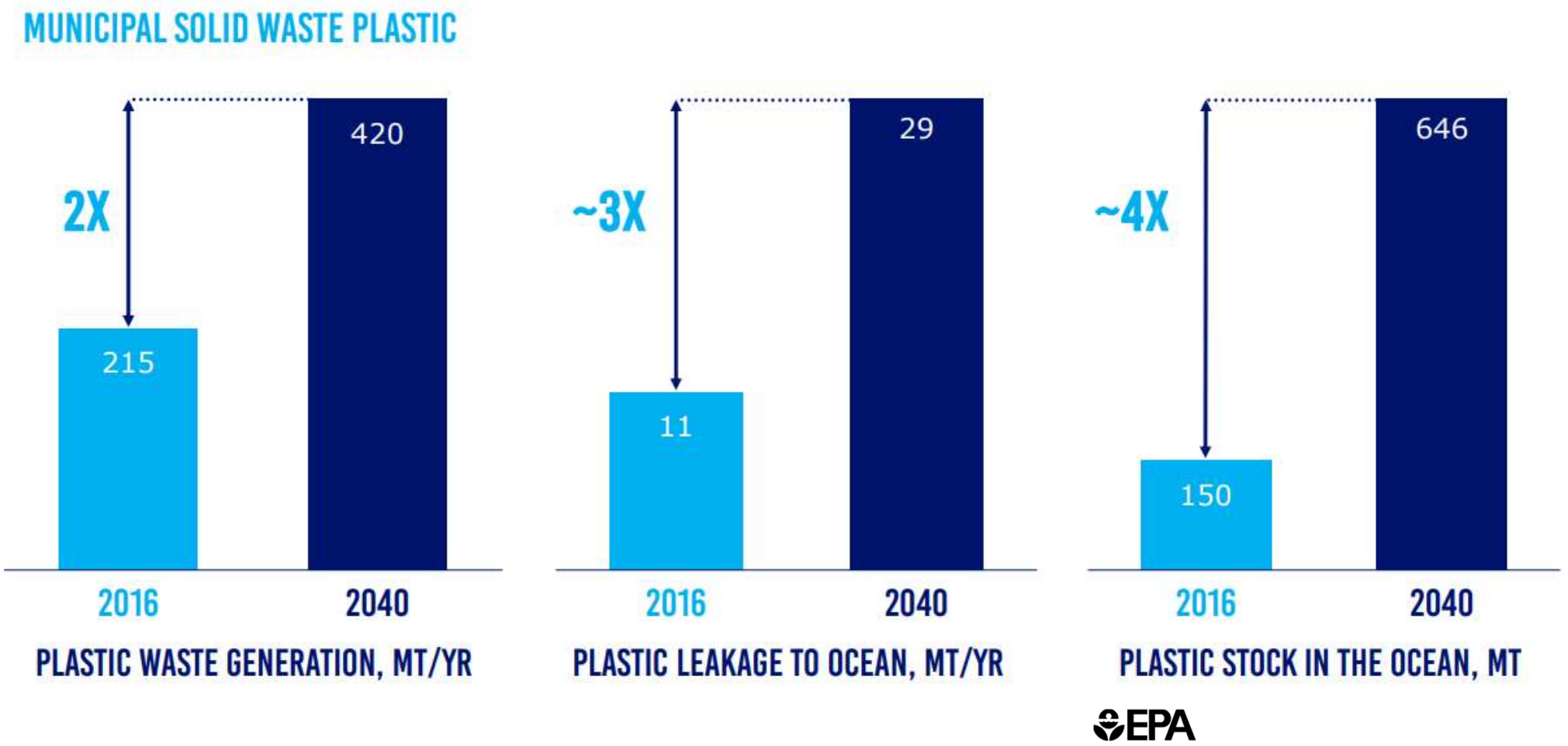
- Pollute landscapes
- Kill wildlife
- Deteriorate habitats of plants and animals
- Microplastics are everywhere, including drinking water and our blood

EPA

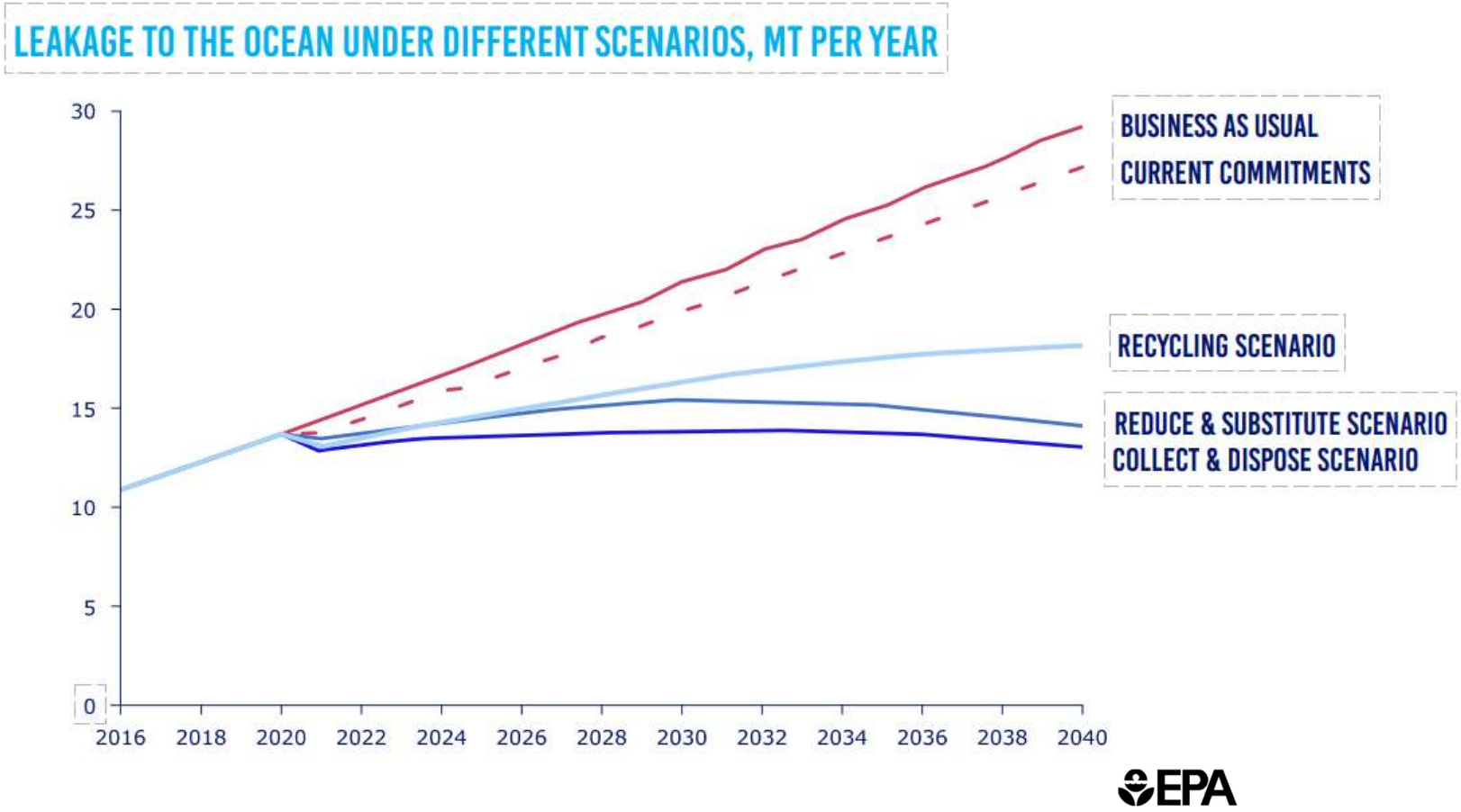
Plastic Pollution

EPA

Plastic pollution will further increase in the future

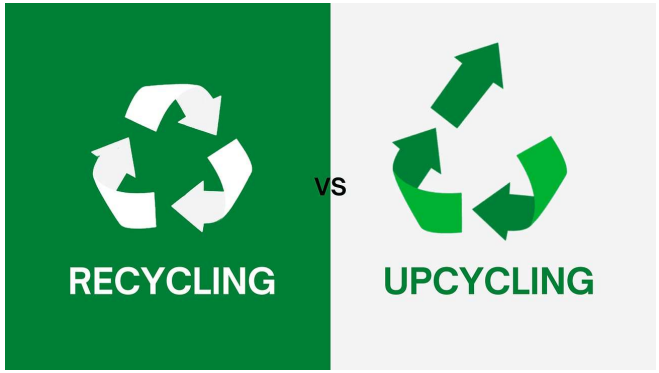


Plastic pollution



Solutions to Plastic Pollution

- Ban the excessive use of plastics
- Burn or bury
- Bio-solutions
- Recycling/Upcycling

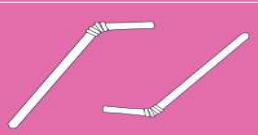


https://solenvn.com/, www.diversitech-global.com

Recycling of Plastics

- In 1988, the Society of the Plastics Industry (2010, changed to Plastics Industry Association), introduced the Resin Identification Coding system
- Raise awareness among consumers of the different kinds of plastic and plastic recycling.
- Ensure we are recycling the maximum amount of plastics.

Recycling of Plastics

Polymer Type	Applications		Resin Identification Code
Polyethylene Terephthalate (PET) & (rPET)	PET plastic bottles, clear plastic bottles, salad trays.		1 PETE
High-Density Polyethylene (HDPE) & (rHDPE)	Milk bottles, bleach, jerry cans, cleaners, general industrial use and shampoo bottles.		2 HDPE
Polyvinyl Chloride (PVC)	Pipes, window and door frames, thermal insulation, automotive parts.		3 PVC
Low-Density Polyethylene (LDPE)	Bin liners, carrier bags and packaging films.		4 LDPE
Polypropylene (PP)	Packing tape, plastic straws, microwavable meal trays and tubs and pails.		5 PP
Polystyrene (PS)	Yoghurt pots, foam fast food boxes, plastic cutlery, protective packaging for electronics and toys.		6 PS
Unallocated References	Other plastics that do not fall into the above.		7 OTHER

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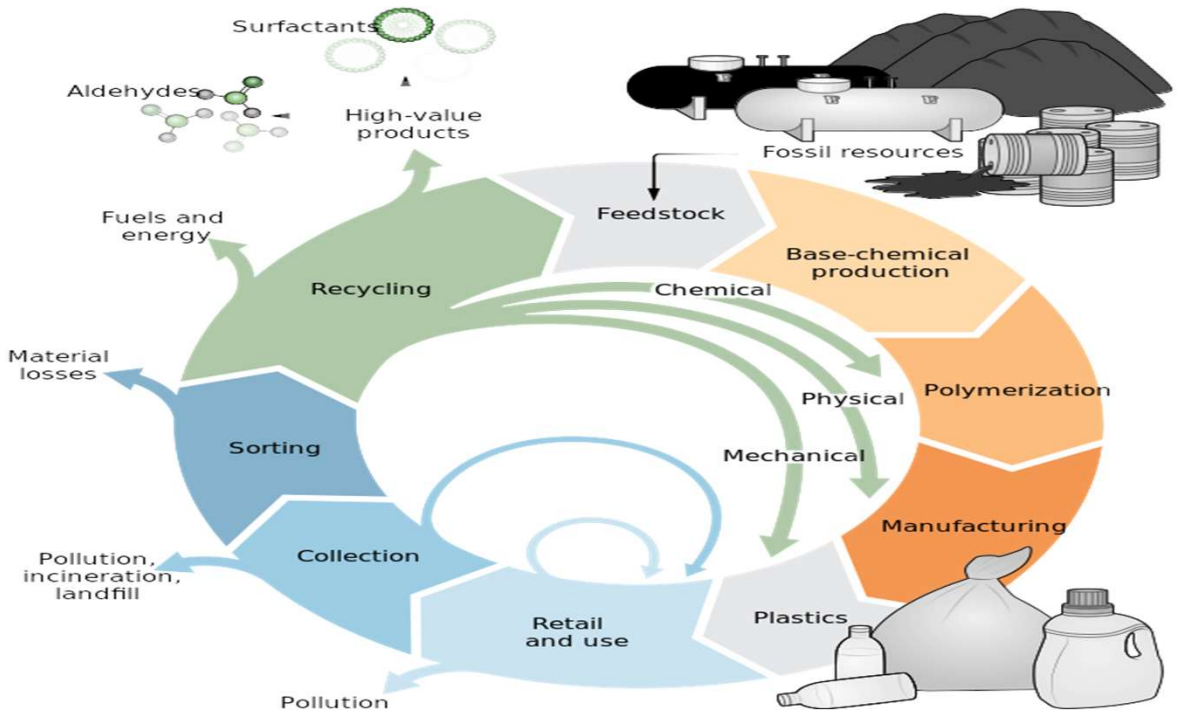

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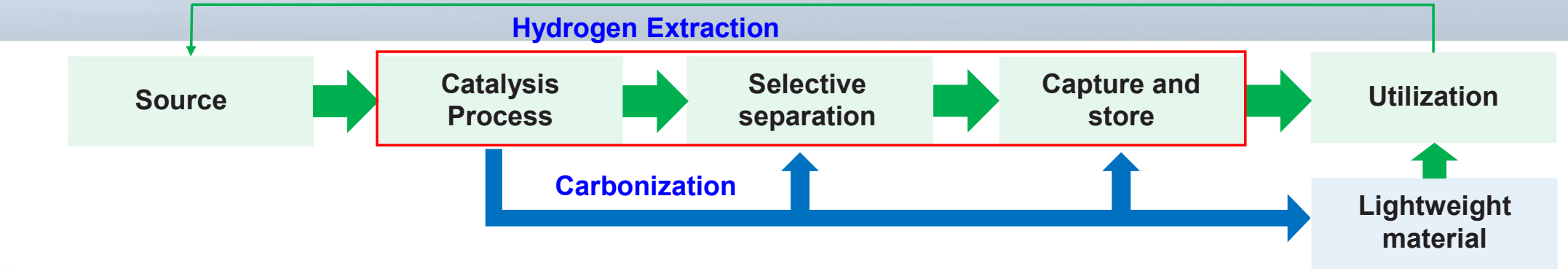

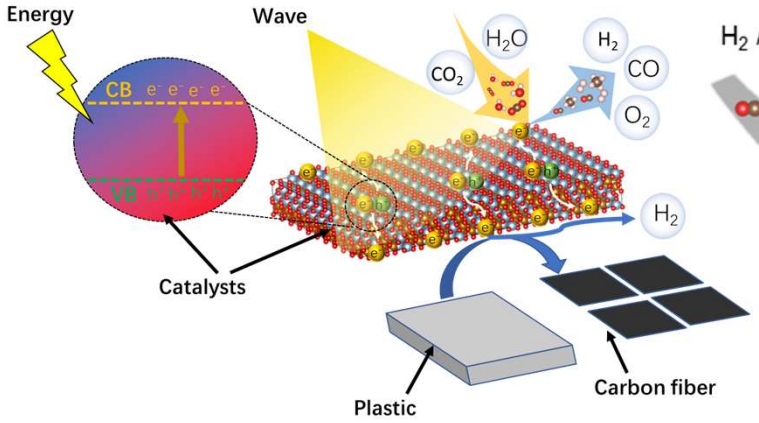

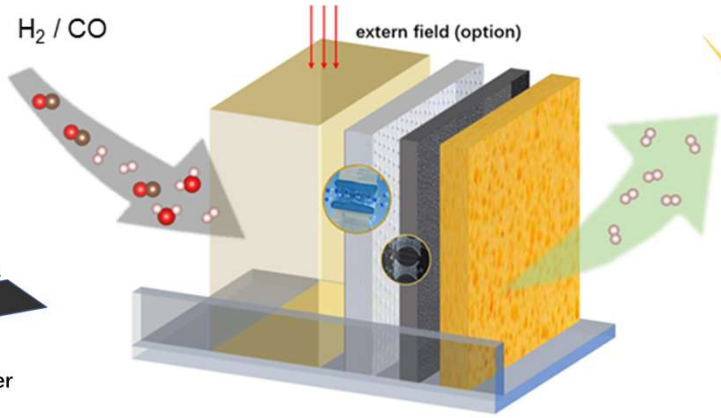

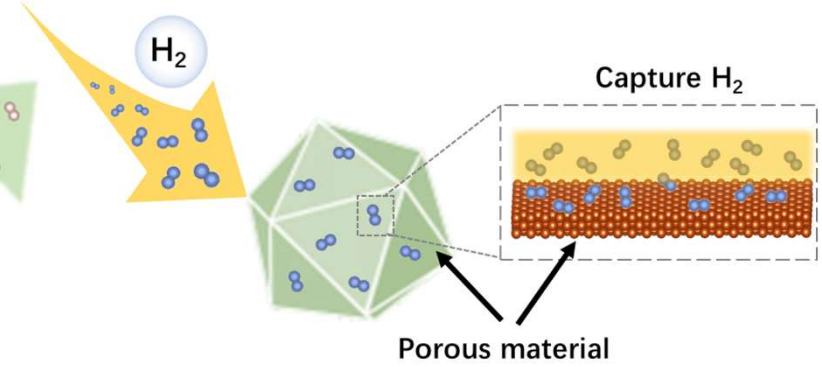

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