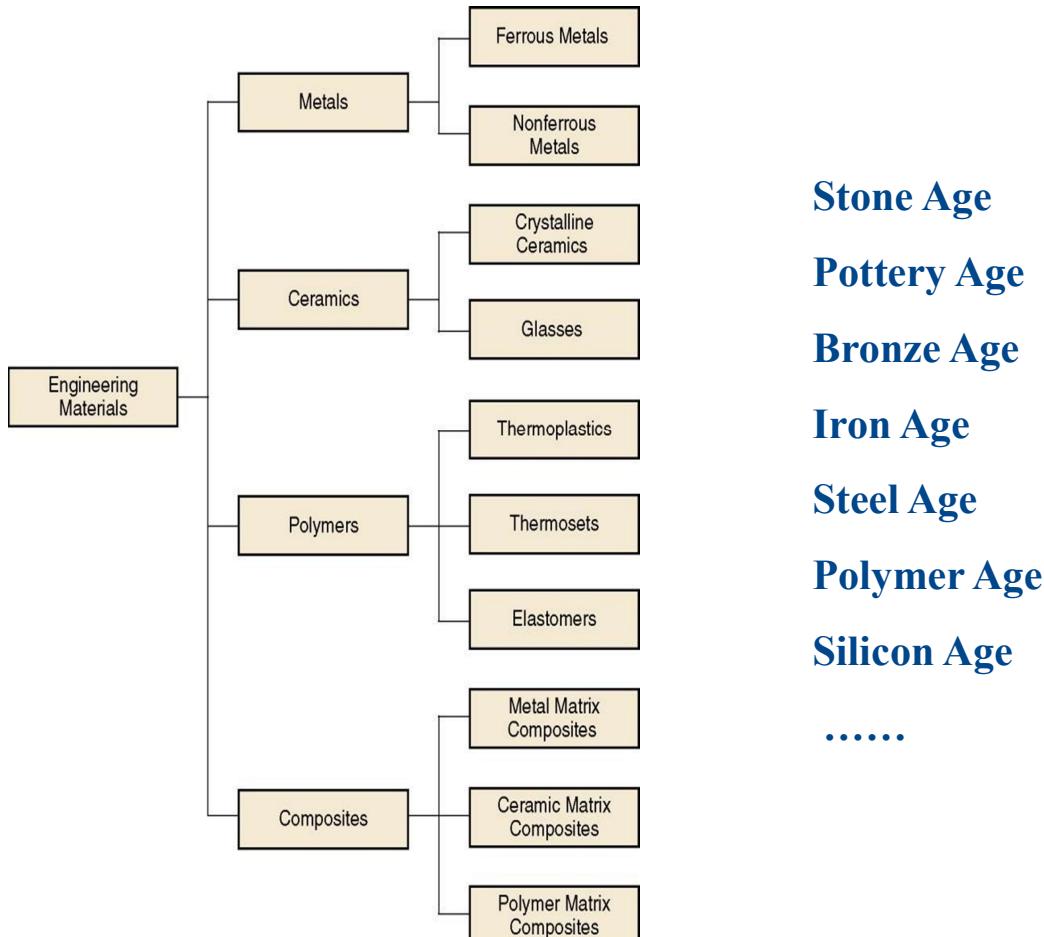
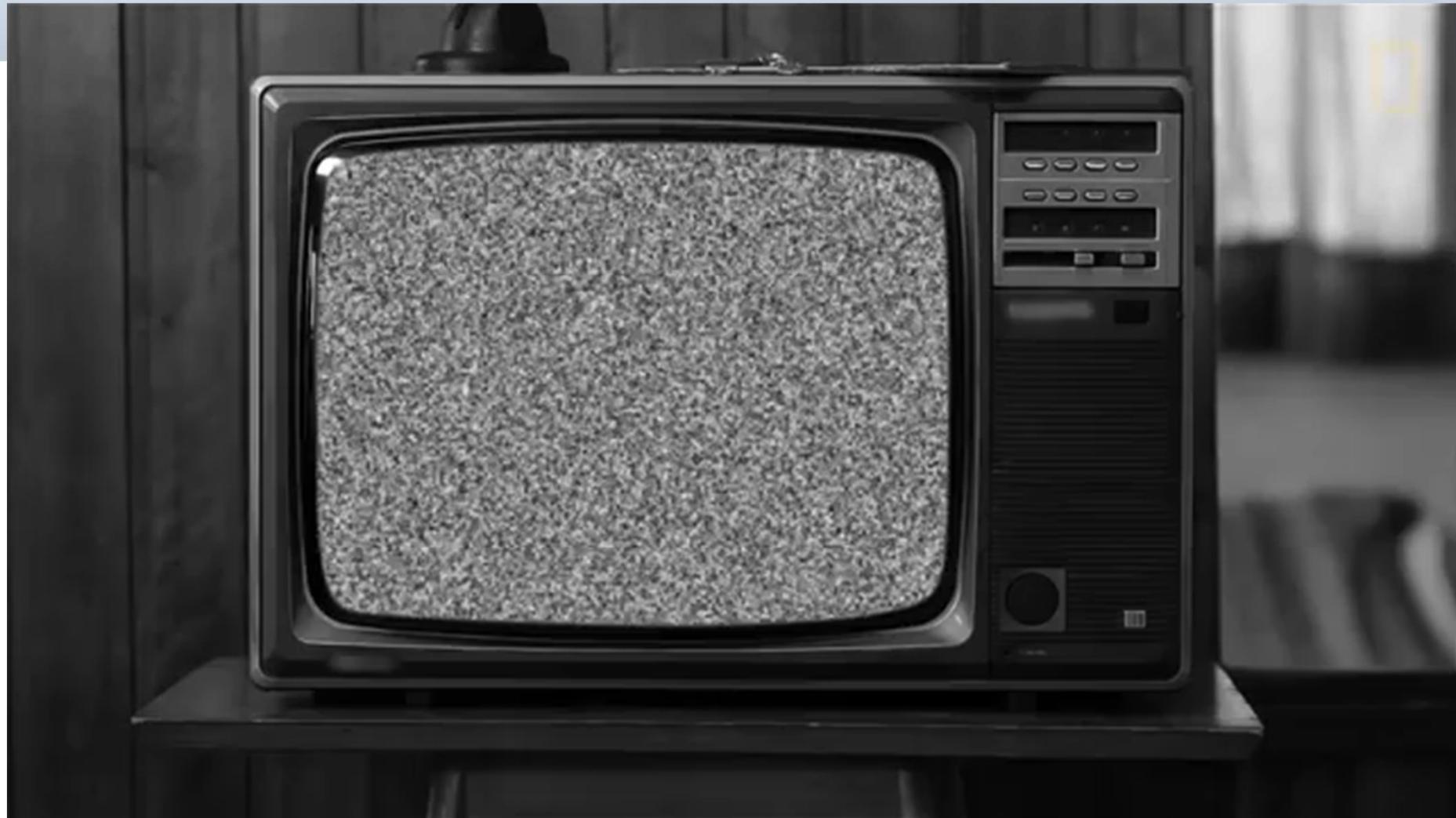


# Materials and civilization



- 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

2024-9-9

# 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

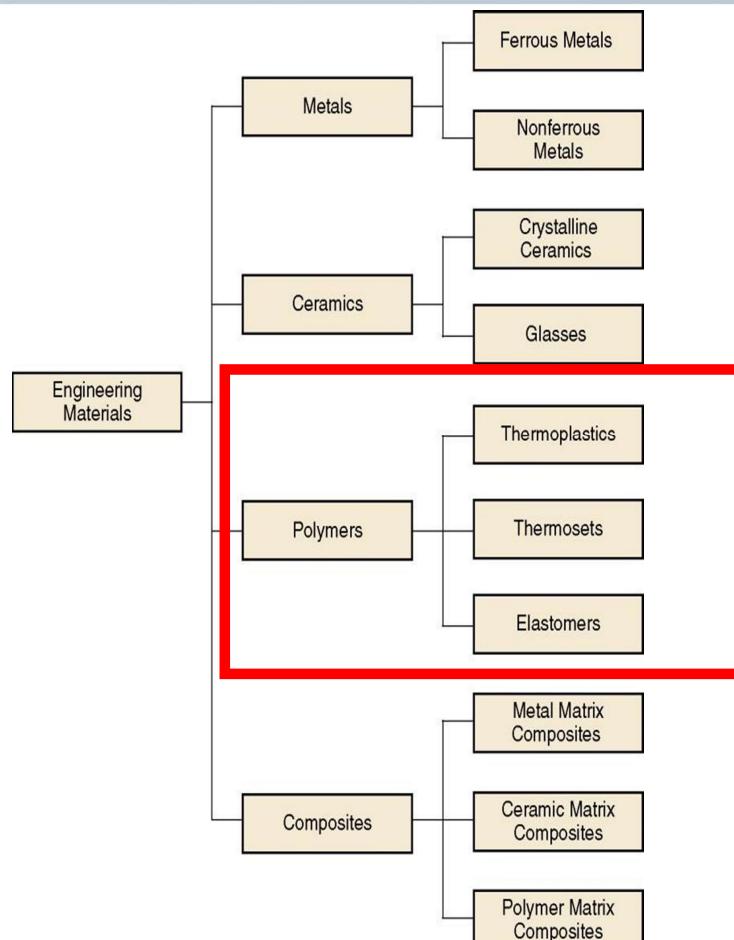
# Table of content

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# Table of content

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# Polymer and civilizations



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

.....

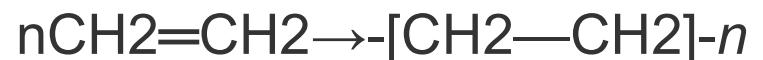
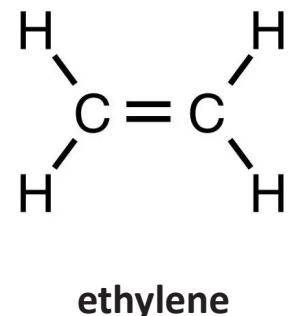
M.P. Groover, 5th edition, John Wiley & Sons Inc. (2007).

# Development of Polymer

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

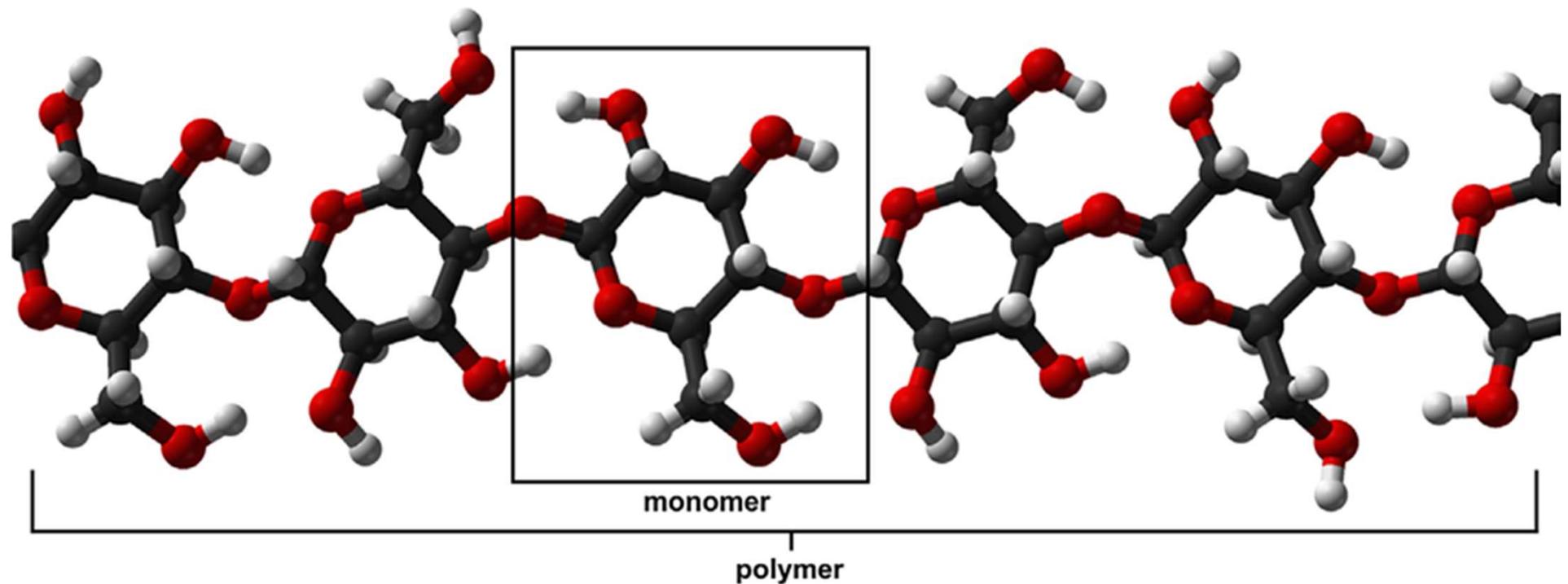
Molecular weight

Property



**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**

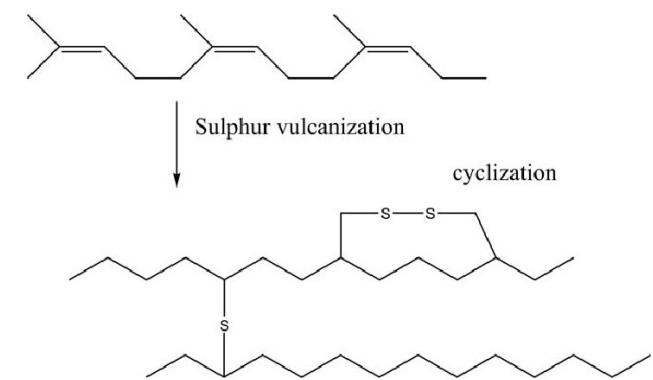
Human-made polymers. **Plastic** is the most common and widely used synthetic polymer.



<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)



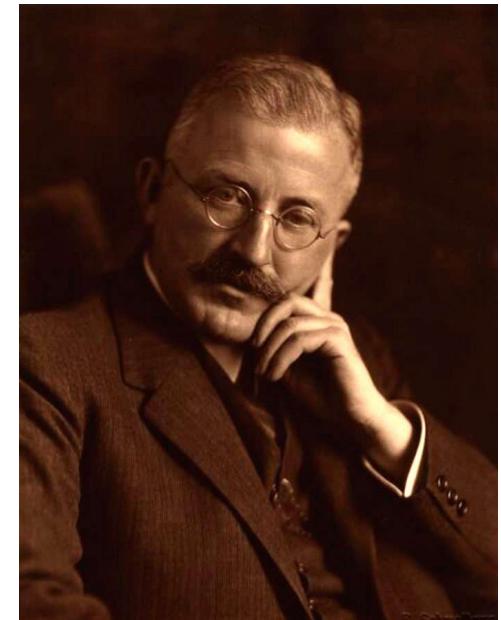
[www.taiwanpu.com](http://www.taiwanpu.com)

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

# 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

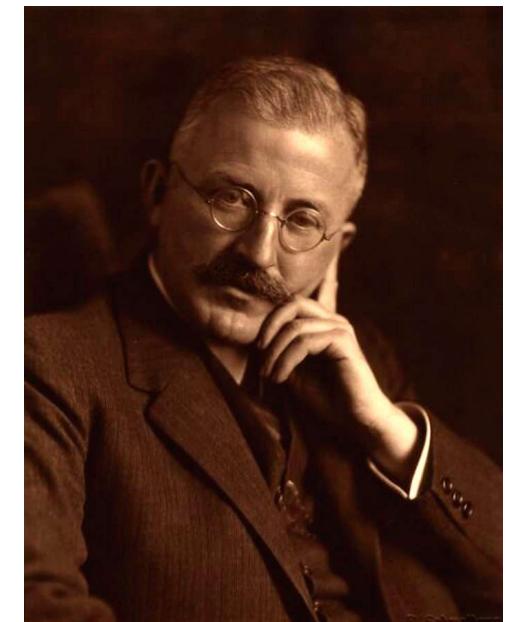


Hermann Staudinger

# 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**

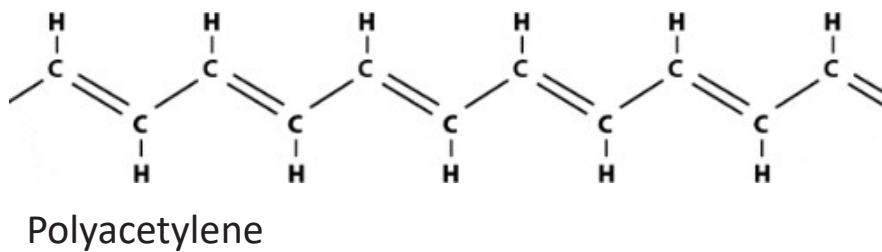
- Winner of the Nobel Prize in 1974



Paul J Flory

# Development of Synthetic Polymers

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



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

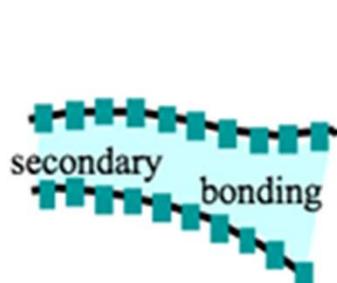
<https://www.nobelprize.org/>

# Table of content

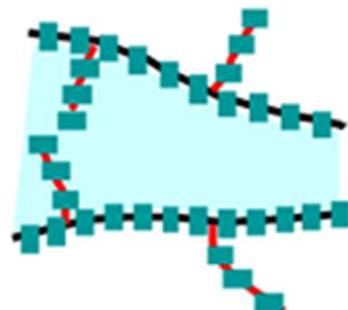
- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# Polymer molecule structure

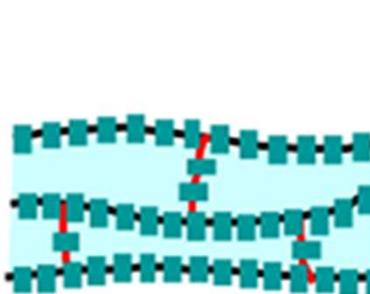
- Molecule structure



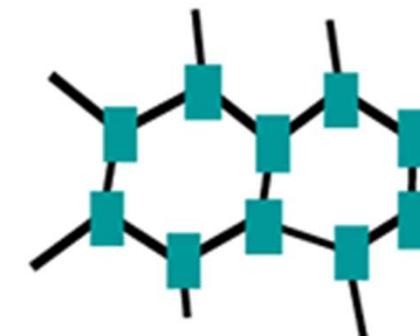
Linear



Branched



Cross-Linked



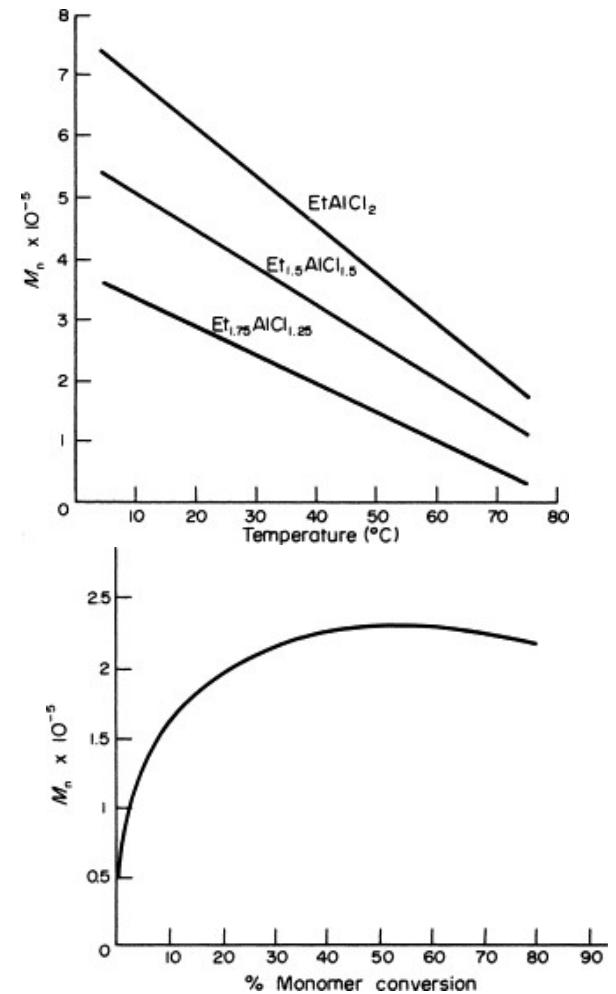
Network

- **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**

# Polymer Molecular Weight

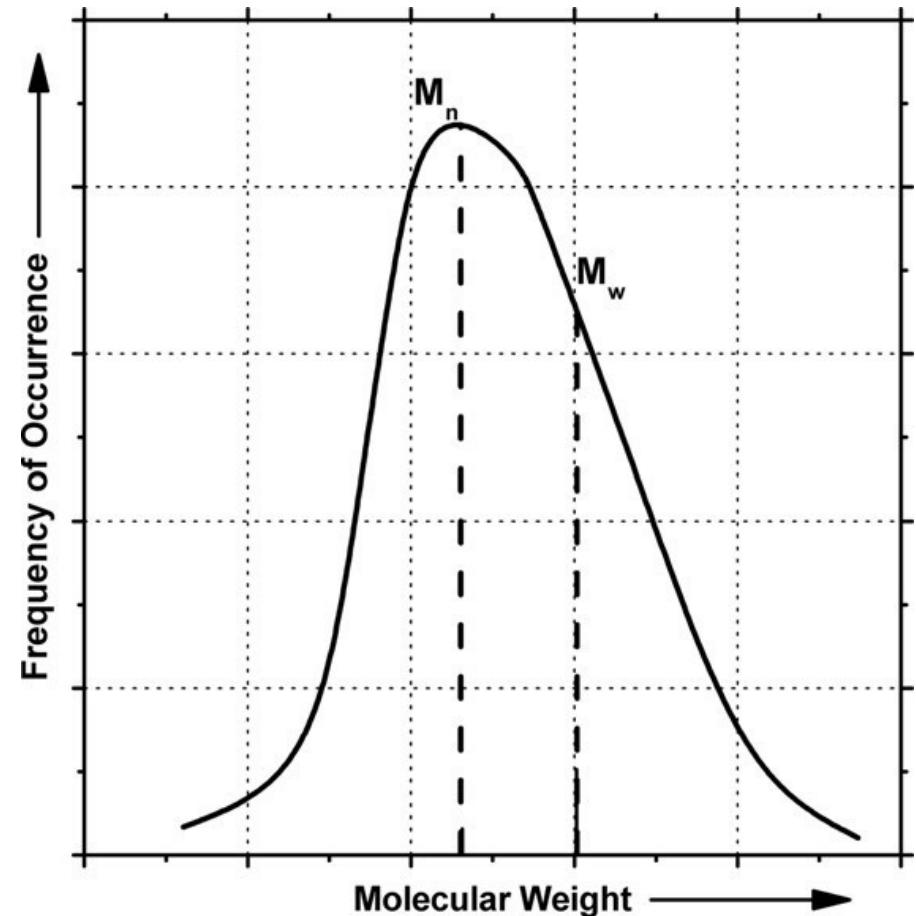
- Polymer Molecular Weight refers to the sum of the atomic weights of individual atoms in a polymer molecule
- A fundamental property of polymers
- Molecular weight determined multiple factors such as solvent, monomer concentration, polymerization temperature, and monomer conversion.

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



# Polymer Molecular Weight

- Number-average weight  $M_n$

where:

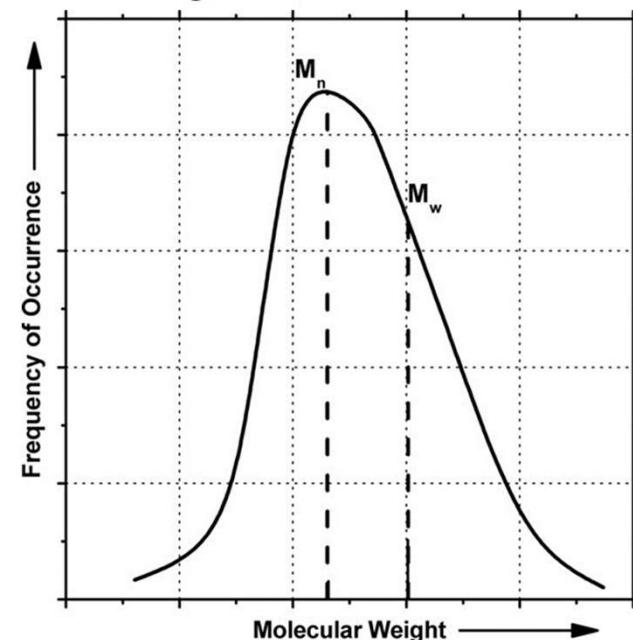
$i$  is the number of polymer molecules

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

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

- Weight-average weight  $M_w$

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

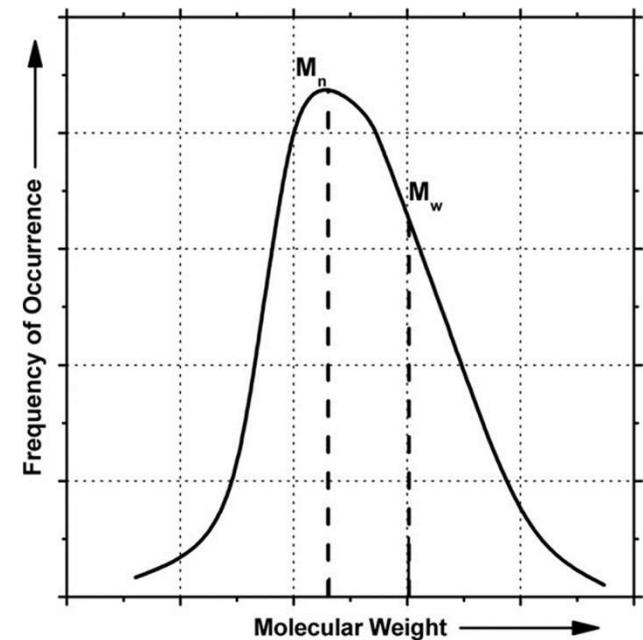


# Polymer Molecular Weight

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

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

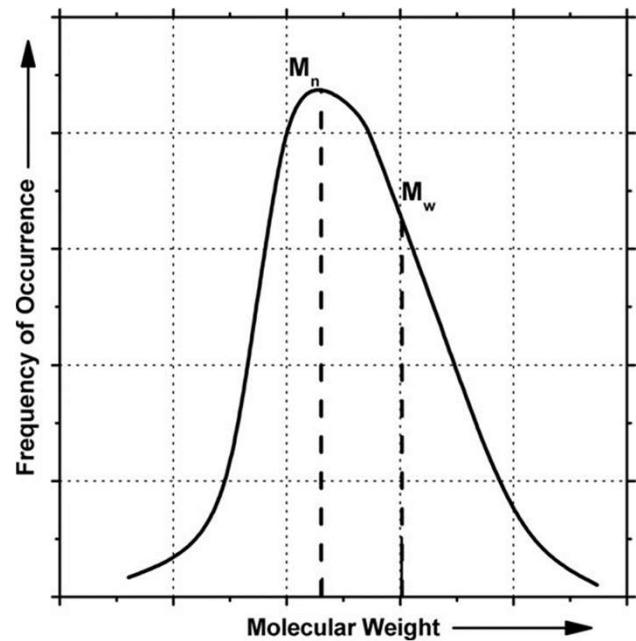
- PDI is unitless, should be 1 when Molecular weight is evenly distributed.



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

# Polymer Molecular Weight

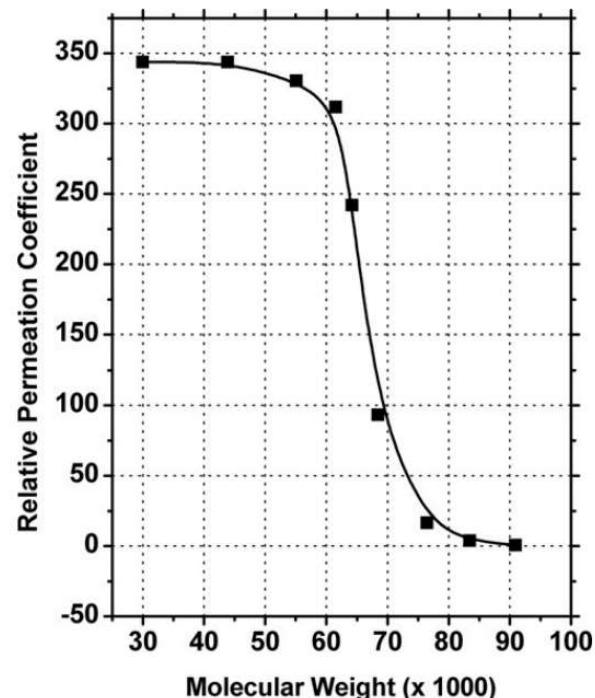
- Narrow distribution often means better properties
- Lower end acts as plasticizer, softening material
- Higher end contribute to the processing difficulties, because higher weight indicates higher viscosity



<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.

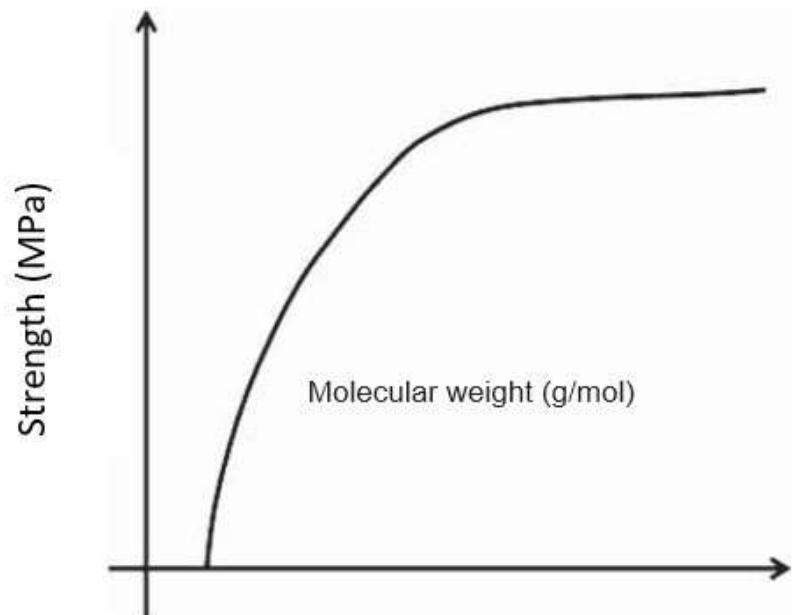


**Figure 2.15** Water permeation of ethylene–vinyl alcohol copolymer vs. polymer molecular weight.<sup>6</sup>

# Polymer Molecular Weight

- Tensile strength ( $\sigma$ ): 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

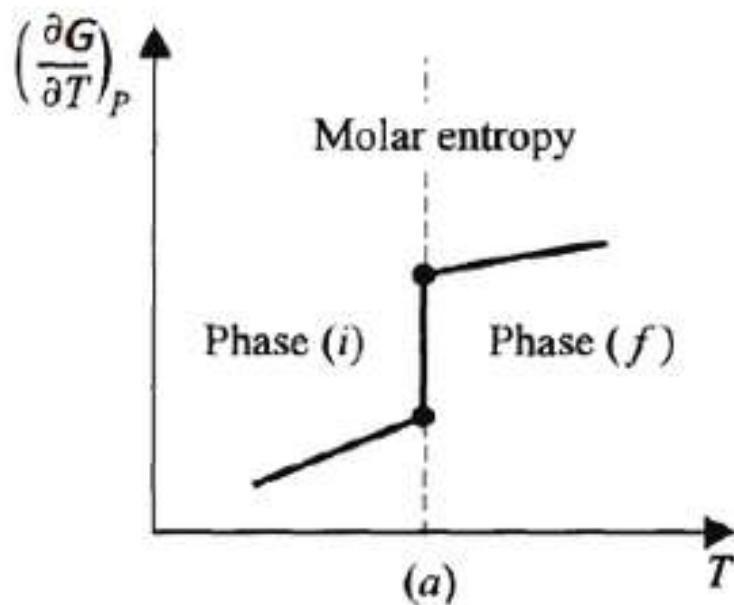
Number of Carbons in Chain	State and Properties of Material	Applications
1–4	Simple gas	Bottled gas for cooking
5–11	Simple liquid	Gasoline
9–16	Medium-viscosity liquid	Kerosene
16–25	High-viscosity liquid	Oil and grease
25–50	<u>Crystalline solid</u>	<u>Paraffin wax candles</u>
50–1000	Semicrystalline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

# Table of content

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# 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

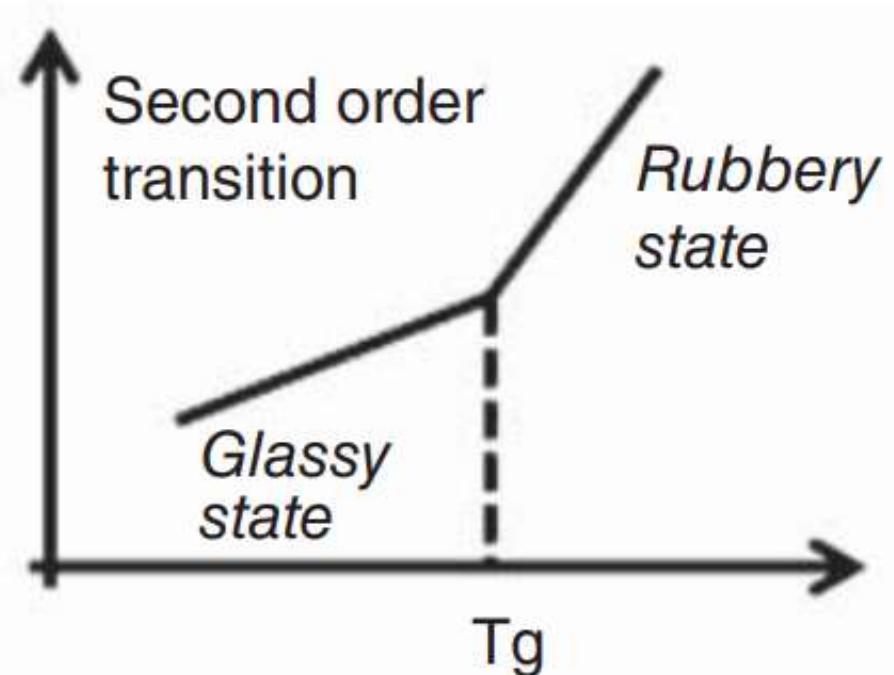
- Glassy state
  - ✓ Frozen state
  - ✓ Polymer is brittle and hard
  - ✓ Like glass
- Rubbery state
  - ✓ Polymer chain wiggles around
  - ✓ Polymer becomes soft



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

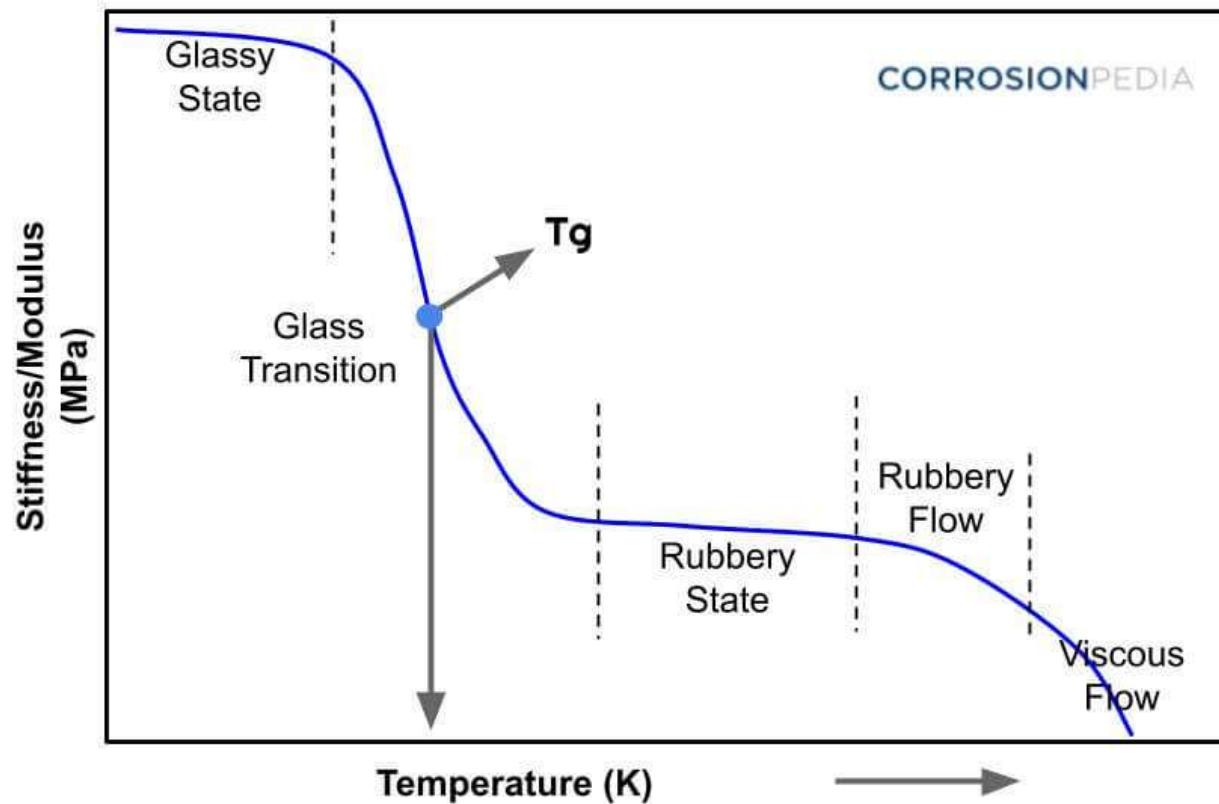
# Thermal Properties of Polymers

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



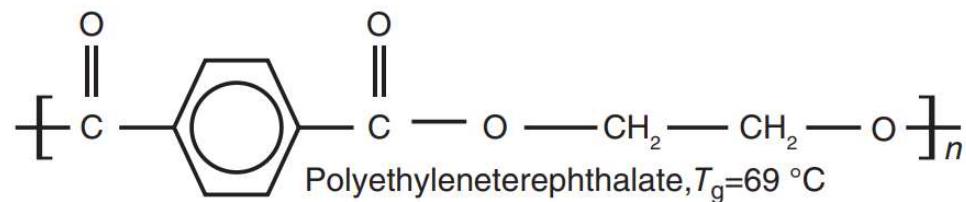
# Thermal Properties of Polymers

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



<https://www.corrosionpedia.com/>

# Thermal Properties of Polymers

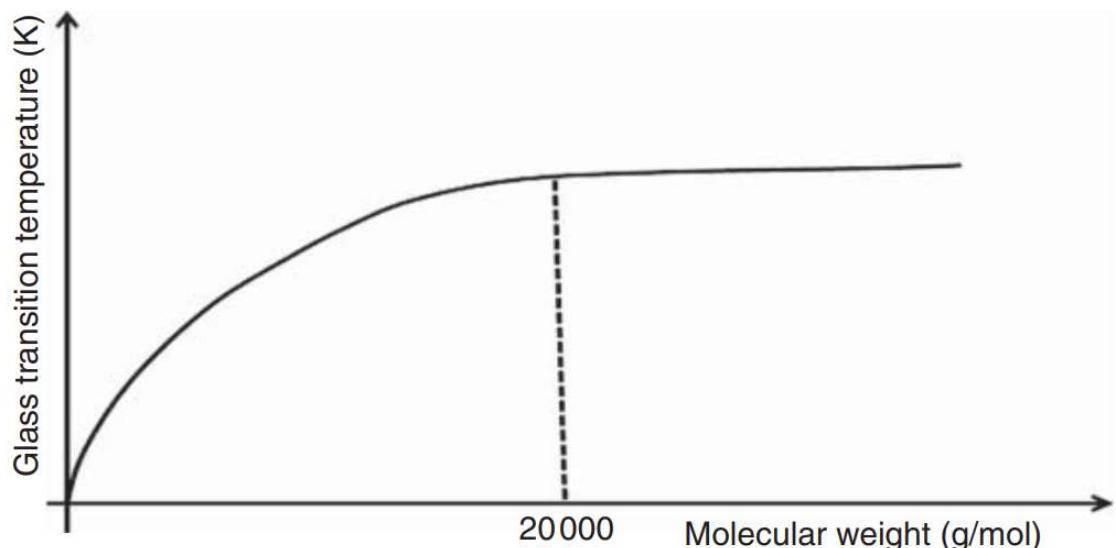


Region	Polymer	Application
Glassy	Poly(methyl methacrylate)	Plastic
Glass transition	Poly(vinyl acetate)	Latex paint
Rubbery plateau	Cross-poly(butadiene- <i>stat</i> -styrene)	Rubber bands
Rubbery flow	Chicle <sup>a</sup>	Chewing gum
Viscous flow	Poly(dimethylsiloxane)	Lubricant

46

## Factors affecting T<sub>g</sub>

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



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

# Table of content

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# Table of content

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# 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



The Institution of  
Engineering and Technology

# 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

- Development of Polymer
- Polymer Physics
- Polymer Transitions
- Polymer Synthesis
- Use of Plastics
- Recycling/Upcycling of Plastics

# Limitations of Plastics

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



# Plastic Pollution



> 80% waste!

# Plastic Pollution

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

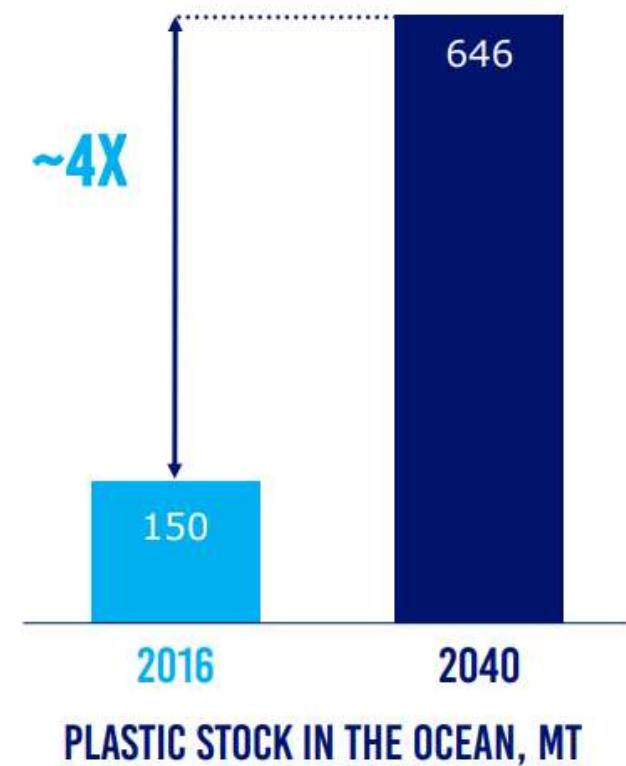
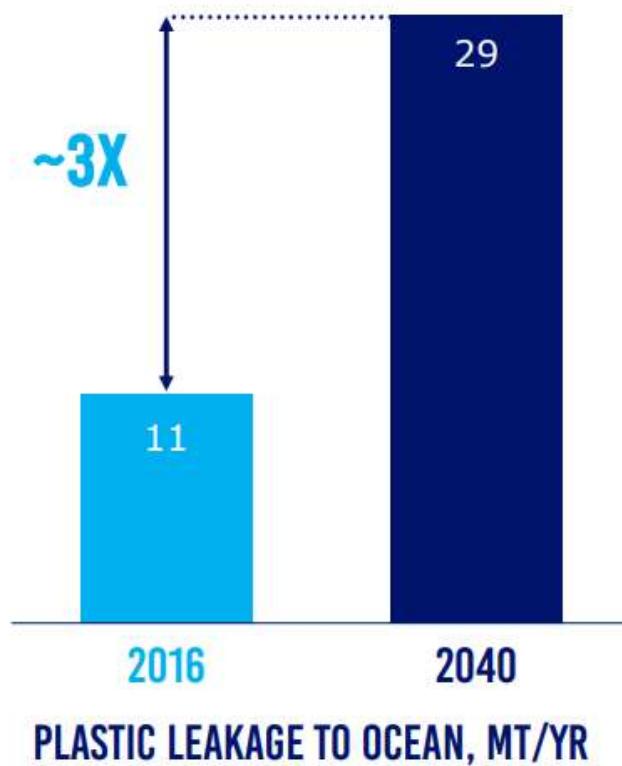
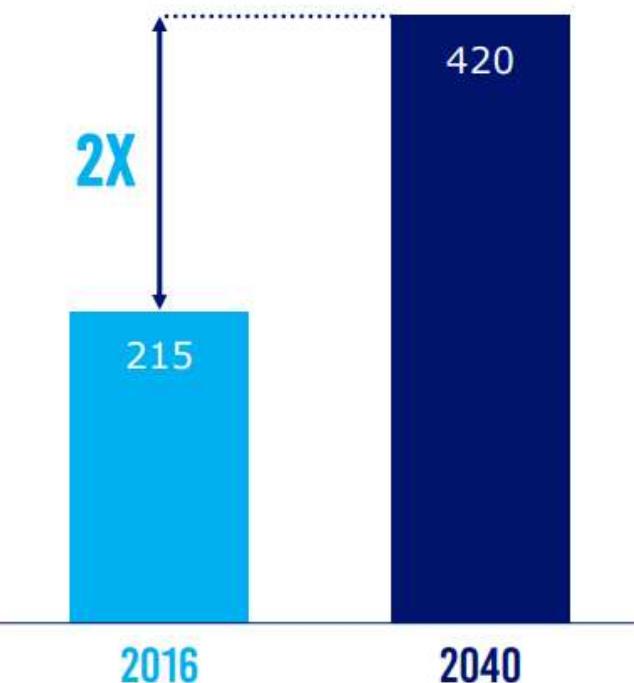


# Plastic Pollution

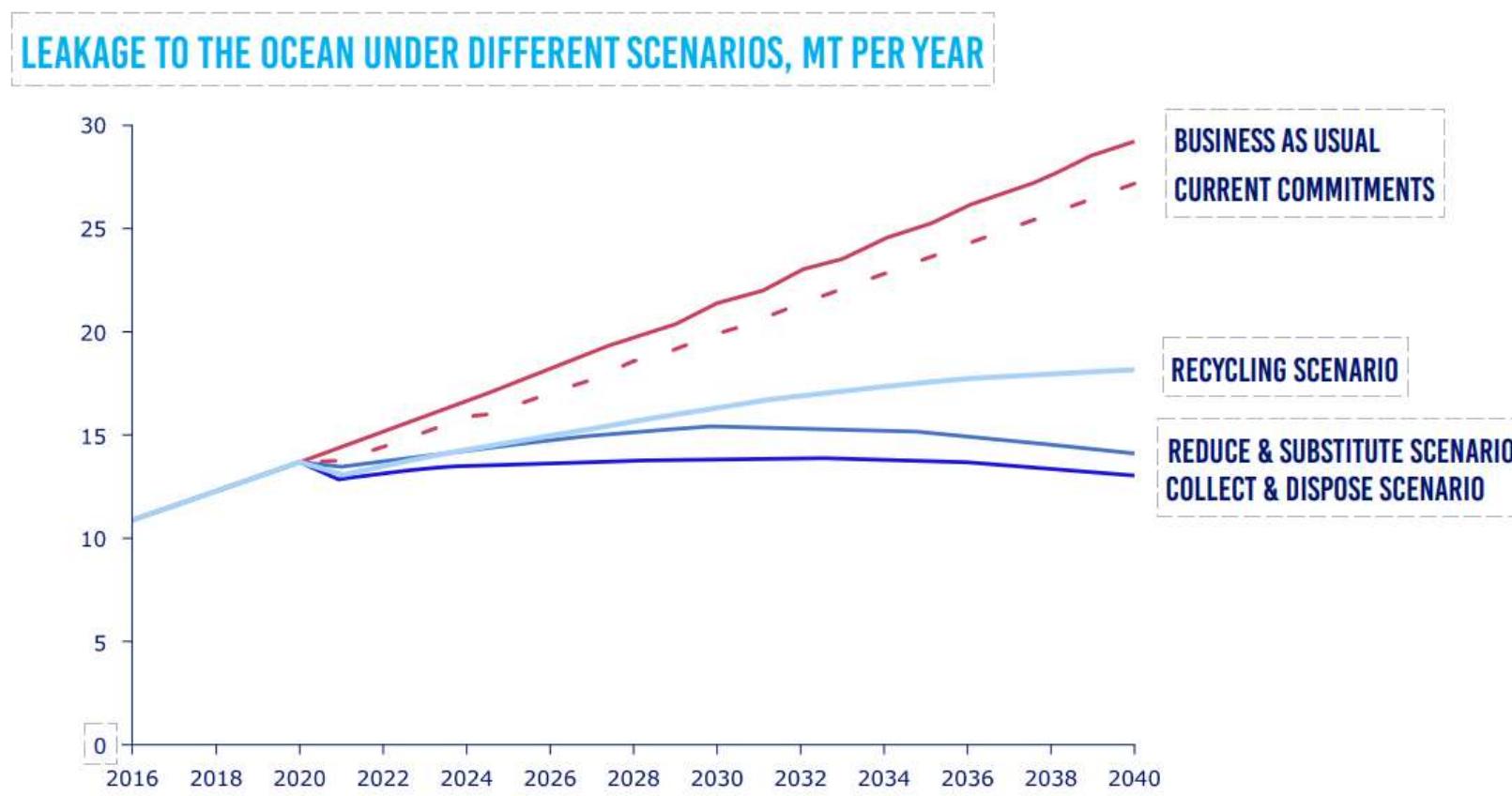


# Plastic pollution will further increase in the future

## MUNICIPAL SOLID WASTE PLASTIC



# Plastic pollution



# Solutions to Plastic Pollution

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



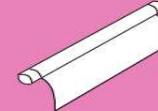
<https://solenvn.com/>, www.diversitech-global.com

# 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.

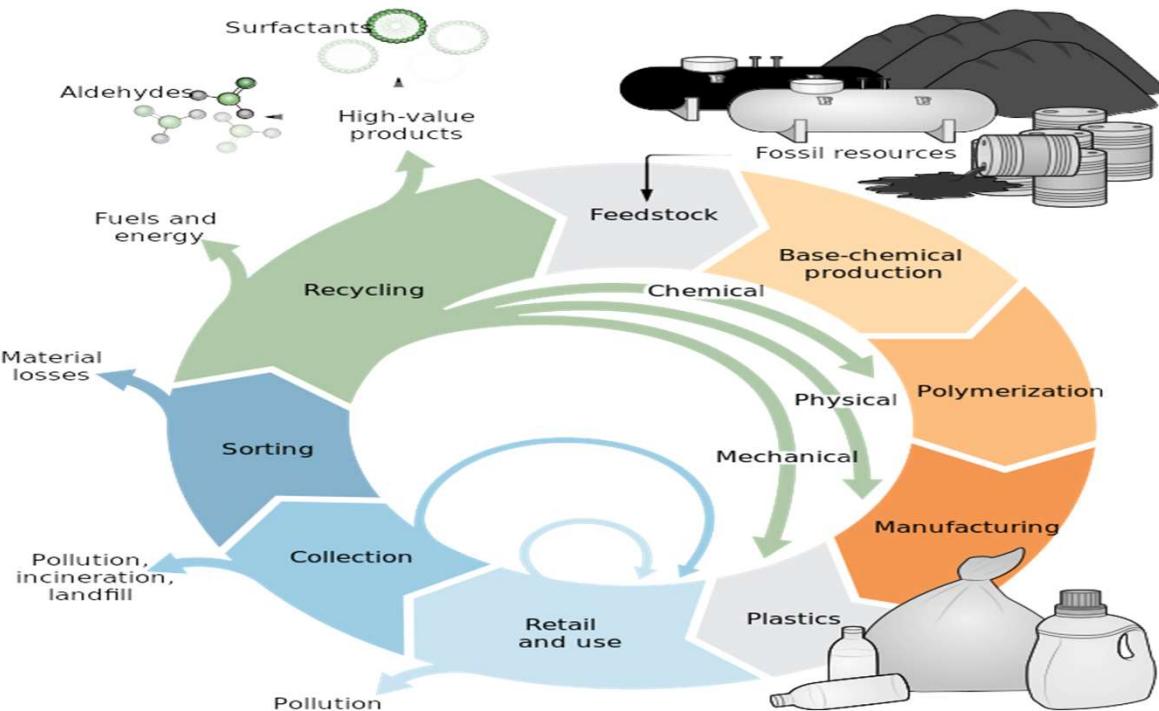


# Recycling of Plastics

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

## Garbage classification





**Plastic waste recycling is gaining momentum, Volume: 381, Issue: 6658, Pages: 607-608, DOI: (10.1126/science.adj2807), Science, August 2023**

Credit to Prof. Gao

# Academic and Industrial Relevance

nature

Explore content ▾ About the journal ▾ Publish with us ▾

nature > perspectives > article

Perspective | Published: 30 March 2022

## Critical advances and future opportunities in upcycling commodity polymers

Coralie Jehanno, Jill W. Alty, Martijn Roosen, Steven De Meester✉, Andrew P. Dove, Eugene Y.-X. Chen, Frank A. Leibfarth✉ & Haritz Sardon✉

Nature 603, 803–814 (2022) | Cite this article

8851 Accesses | 1 Citations | 77 Altmetric | Metrics

nature

Explore content ▾ About the journal ▾ Publish with us ▾

nature > articles > article

Article | Published: 27 April 2022

## Machine learning-aided engineering of hydrolases for PET depolymerization

Hongyuan Lu, Daniel J. Diaz, Natalie J. Czarnecki, Congzhi Zhu, Wantae Kim, Raghav Shroff, Daniel J. Acosta, Bradley R. Alexander, Hannah O. Cole, Yan Zhang, Nathaniel A. Lynd, Andrew D. Ellington & Hal S. Alper✉

Nature 604, 662–667 (2022) | Cite this article

41k Accesses | 2 Citations | 2042 Altmetric | Metrics

nature catalysis

Explore content ▾ About the journal ▾ Publish with us ▾ Subscribe

nature > nature catalysis > articles > article

Article | Published: 12 October 2020

## Catalytic upcycling of high-density polyethylene via a processive mechanism

Akalanka Tennakoon, Xun Wu, Alexander L. Paterson, Smita Patnaik, Yuchen Pei, Anne M. LaPointe, Salai C. Ammal, Ryan A. Hackler, Andreas Heyden, Igor I. Slowing, Geoffrey Baron Peters, Wenyu Huang✉, Aaron D. Sadow✉ & Frédéric A. P.

Nature Catalysis 3, 893–901 (2020) | Cite this article

8016 Accesses | 73 Citations | 98 Altmetric | Metrics



From the journal:  
Energy & Environmental Science

Science AAAS

## Plastic waste as a feedstock for solar-driven H<sub>2</sub> generation†‡

Taylor Uekert, Moritz F. Kuehnel, Moritz F. Kuehnel, David W. Wakerley, and Erwin Reisner

## 5 new technologies that are making an impact

C&EN takes a look at innovation emerging from the chemical industry's big players

November 29, 2020 | A version of this story appeared in Volume 98, Issue 46

### MAKING POLYURETHANE RAW MATERIALS FROM OLD BOTTLES

by Alexander H. Tullo



Center for Green Materials

Credit to Prof. Gao

# Upcycling

## What are Plastics?

- Carbon (up to 90%)
- Hydrogen (>10%)

## What can we do?

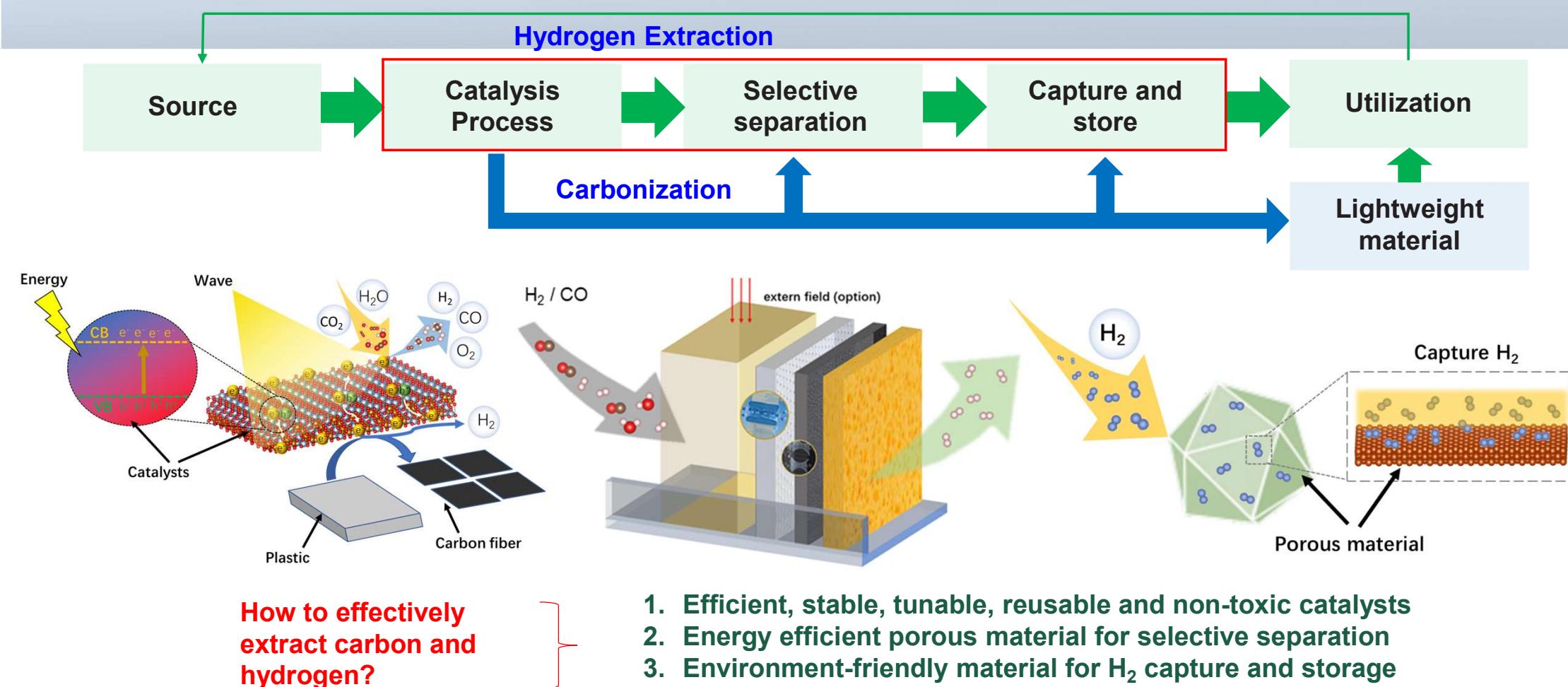
Convert them



Hydrogen  
for fuel

Carbon  
nanomaterials  
for hydrogen  
storage

# Polymer hydrogen extraction and carbonization - GeM (Green e Materials Lab, HKUST (GZ) )



# Upcycling of Plastics



## 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

- $\geq 750$  words
- No cheating allowed
- Statement of AI use
- Deadline is Sep 29<sup>th</sup>, 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

Disclaimer: The contents are provided by third-party AI models such as GPT, HKUST(GZ) has...

Token Usage: 30569/5000000 token Chat Configuration ChatGPT

+ New Conversation input search text

How to write a good Research Method and Justification?

Writing a good research method and justification involves clearly explaining the approach you will take to conduct your research and providing a rationale for why this approach is the most suitable for your study. Here are some key steps to consider when writing a research method and justification:

1. Clearly describe the research method: Provide a detailed description of the research method you plan to use. This may include qualitative, quantitative, or mixed methods, as well as specific techniques, tools, or instruments that will be utilized. Be specific and comprehensive in outlining the steps you will take to collect, analyze, and interpret data.

2. Justify the chosen method: Explain why the selected research method is the most appropriate for addressing the research questions or objectives. Consider factors such as the nature of the research problem, the type of data needed, the availability of resources, and ethical considerations. Highlight the strengths of the chosen method and how it aligns with the goals of the study.

3. Discuss previous research: Provide a review of relevant literature to support the choice of the research method. Discuss how similar methods have been used in previous studies and how they have contributed to the understanding of the research topic. Highlight any gaps in the existing literature that your chosen method can address.

4. Consider ethical considerations: Address any ethical considerations related to the research method, such as informed consent, confidentiality, and participant well-being. Explain how you plan to address these ethical considerations and ensure the ethical conduct of the research.

5. Anticipate limitations: Acknowledge any potential limitations or weaknesses of the chosen research method and discuss how you plan to mitigate these limitations. This demonstrates a thoughtful approach to the research design and enhances the credibility of the study.

6. Be clear and concise: Write in a clear and concise manner, using language that is accessible to your intended audience. Avoid jargon and technical terms that may not be familiar to all readers.

+ New Conversation input search text

① 请帮我整合以...  
② Write the signific...  
③ please reply this ...  
④ 请帮我写一封...  
⑤ sv40 on的功能...

+ New Conversation input search text

① 请帮我整合以...  
② Write the signific...  
③ please reply this ...  
④ 请帮我写一封...  
⑤ sv40 on的功能...

By following these steps, you can effectively write a research method and justification that clearly outlines your approach and provides a solid rationale for the chosen method, contributing to the overall strength and validity of your research study.

2023-12-24 22:20:20

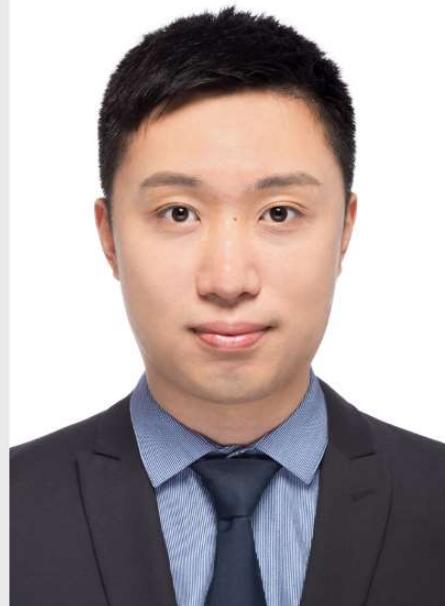
# Guest lecture by Prof. Haoxiang Li on Superconducting Material

- Tomorrow  
(Sep 10<sup>th</sup>, Tue)  
for section L02
- Lecture Hall B
- 9am



THE HONG KONG  
UNIVERSITY OF SCIENCE AND  
TECHNOLOGY (GUANGZHOU)

FACULTY PROFILES



Haoxiang Li

李昊翔

PhD in Physics  
University of Colorado at Boulder, 2017

Assistant Professor

Thrust of Advanced Materials  
Quantum Science and Technology Center

OVERVIEW

PUBLICATIONS

## Next lecture

- No lecture on Sep 14<sup>th</sup>.
- No lecture on Sep 16<sup>th</sup>.
- Next lecture will be on Sep 23<sup>rd</sup>.

# Survey

