The Application of Synthetic Artificial Bacteria in Plastic Degradation

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Year 2 Mphil

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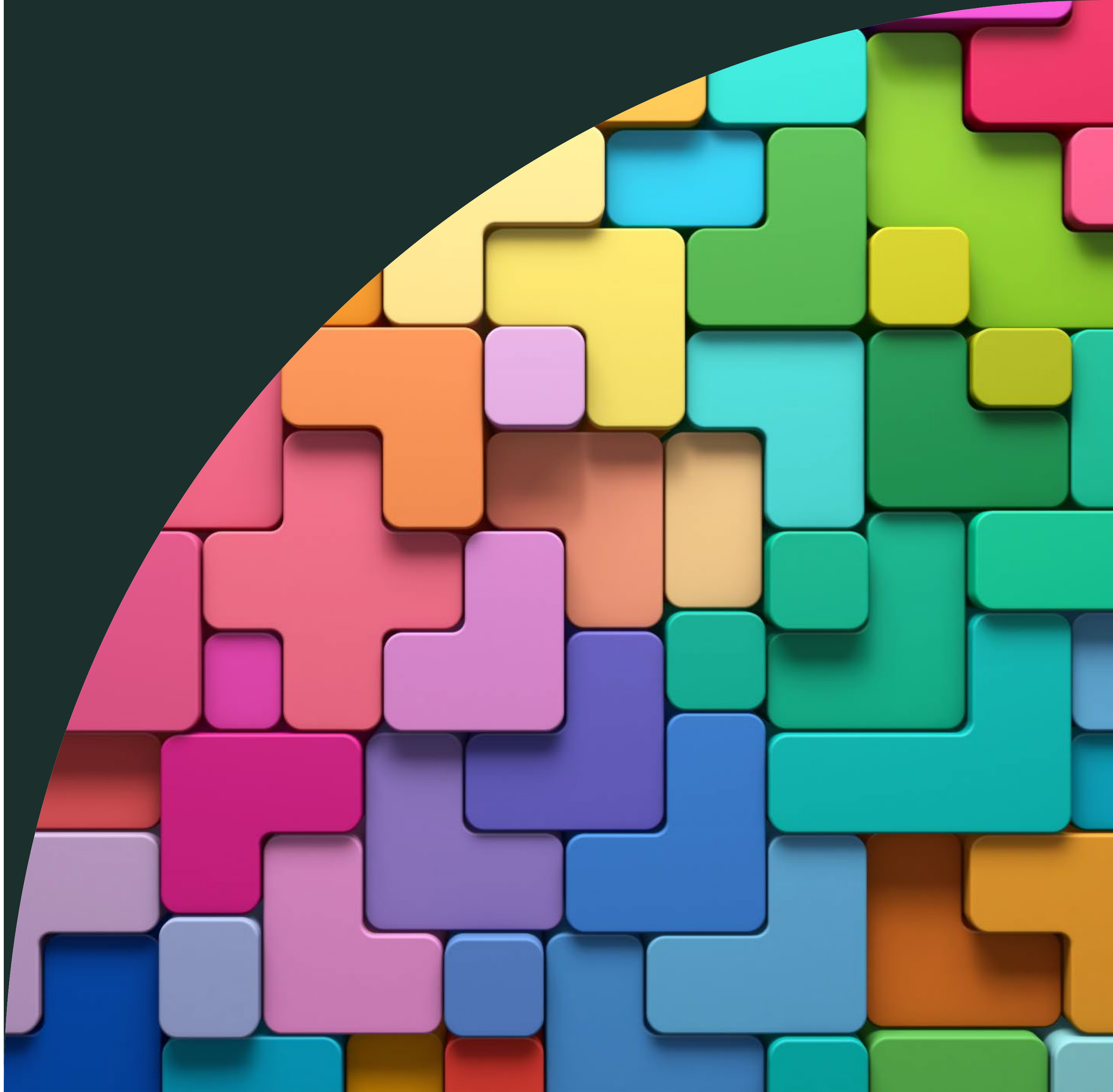


Outline

I. Current situation of plastic pollution

II. Plastic biodegrading by synthesized and nature bacteria

III. The mechanism of bacteria-based plastic degradation

IV. Feasibility of synthesized bacteria application

Synthetic Plastic:
industry and everyday lives

- Widely produced and used since 1950
- Global output 400 Mt per year by 2020
- Polymeric material

✓ Plasticity

✓ Low density

✓ Transparency

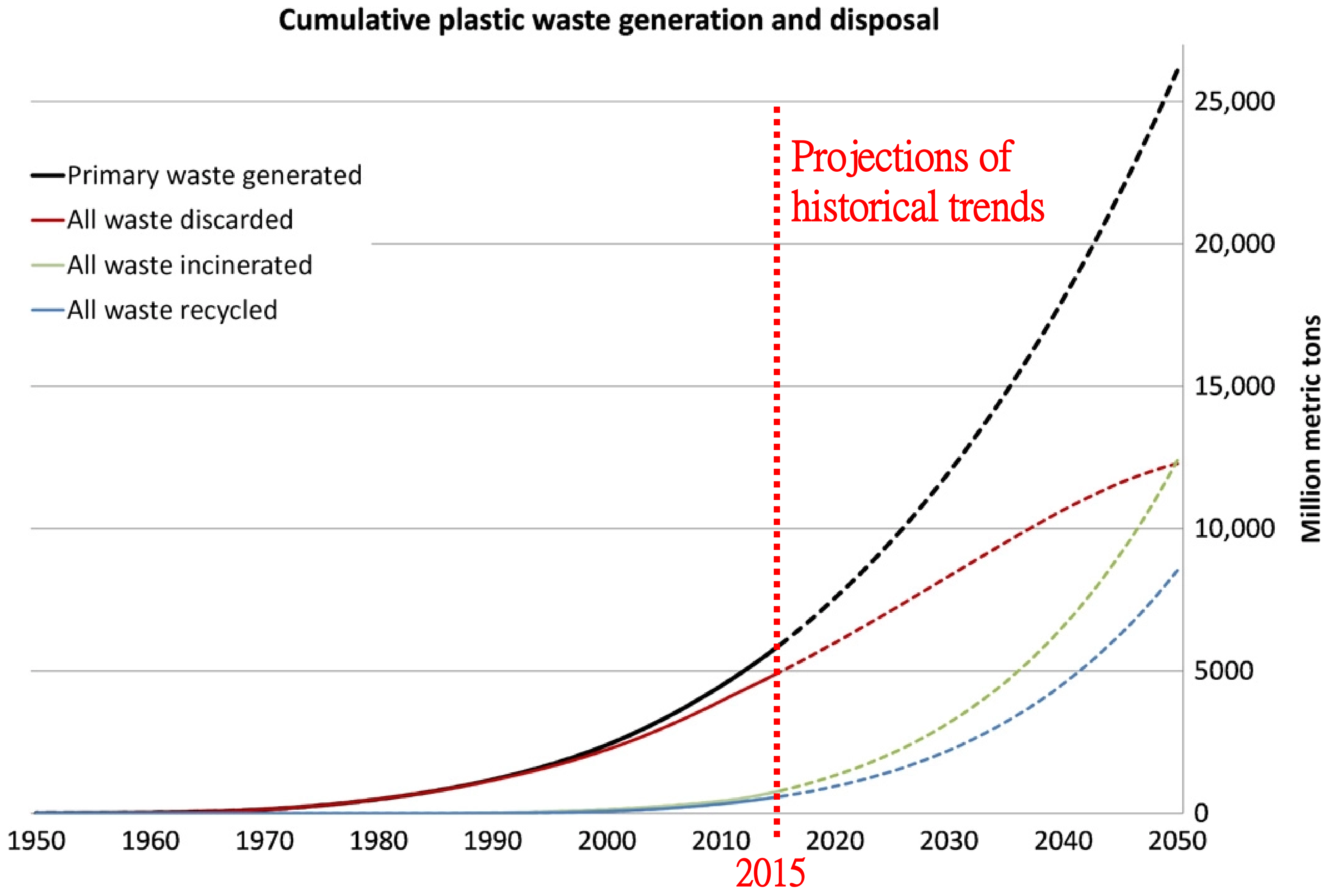
✓ Toughness



“White Pollution”

caused by plastic


Treatments of plastic wastes



(Geyer, R. et al., *Science Advances*, 2017)

- 80% discarded by landfills & nature environment
- Raising portion of plastic incineration
- Very small portion of plastic waste is recycled
- Accumulation of plastic in the environment!

Plastic biodegrading

Biodegradable plastic

- Bio-based plastics
- Petroleum-based plastics

Plastic-degrading microbes

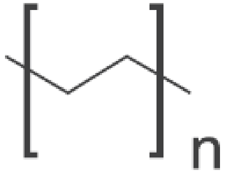
- Natural bacteria
- Synthetic bacteria

Natural bacteria

----From plastic-eating worms

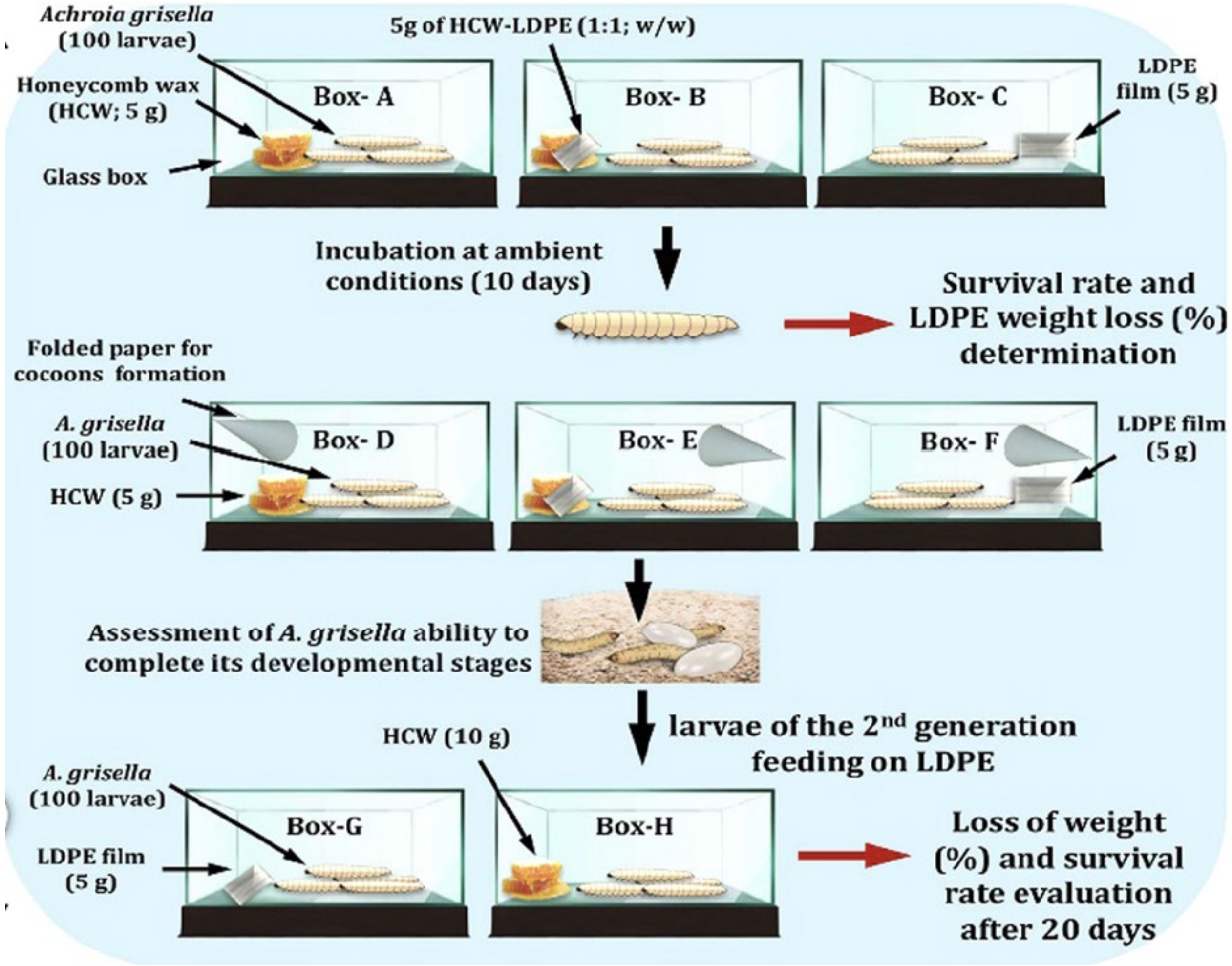
- Waxworms (*Achroia grisella*) is a symbiotic species of honeybees
- The larvae of waxworm feed on honeycomb and other materials found in honeybee colonies

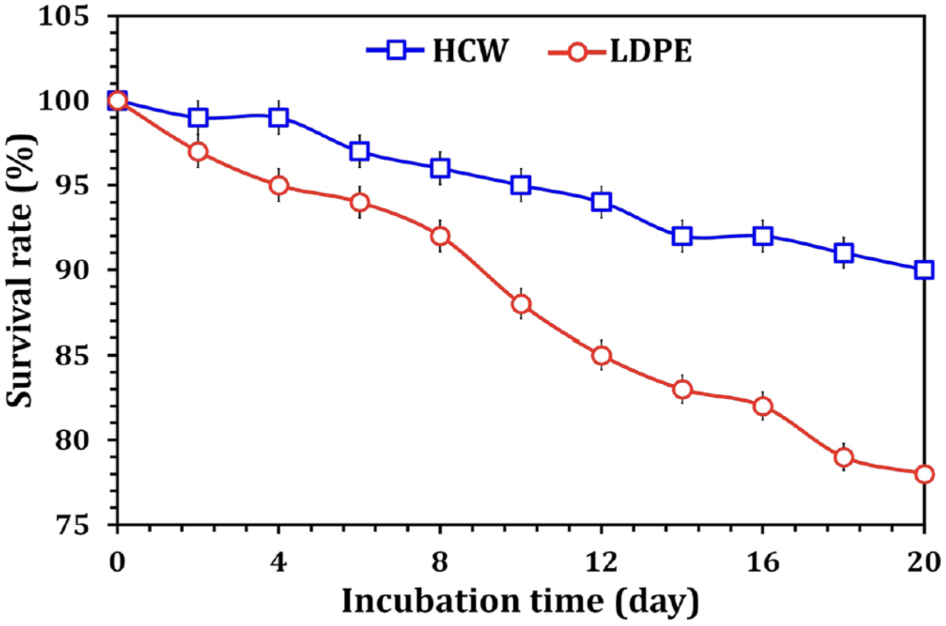
PE



- Waxworms larvae can also feed on polyethylene (PE) to survive
- PE is most commonly produced plastic

Larvae survival test



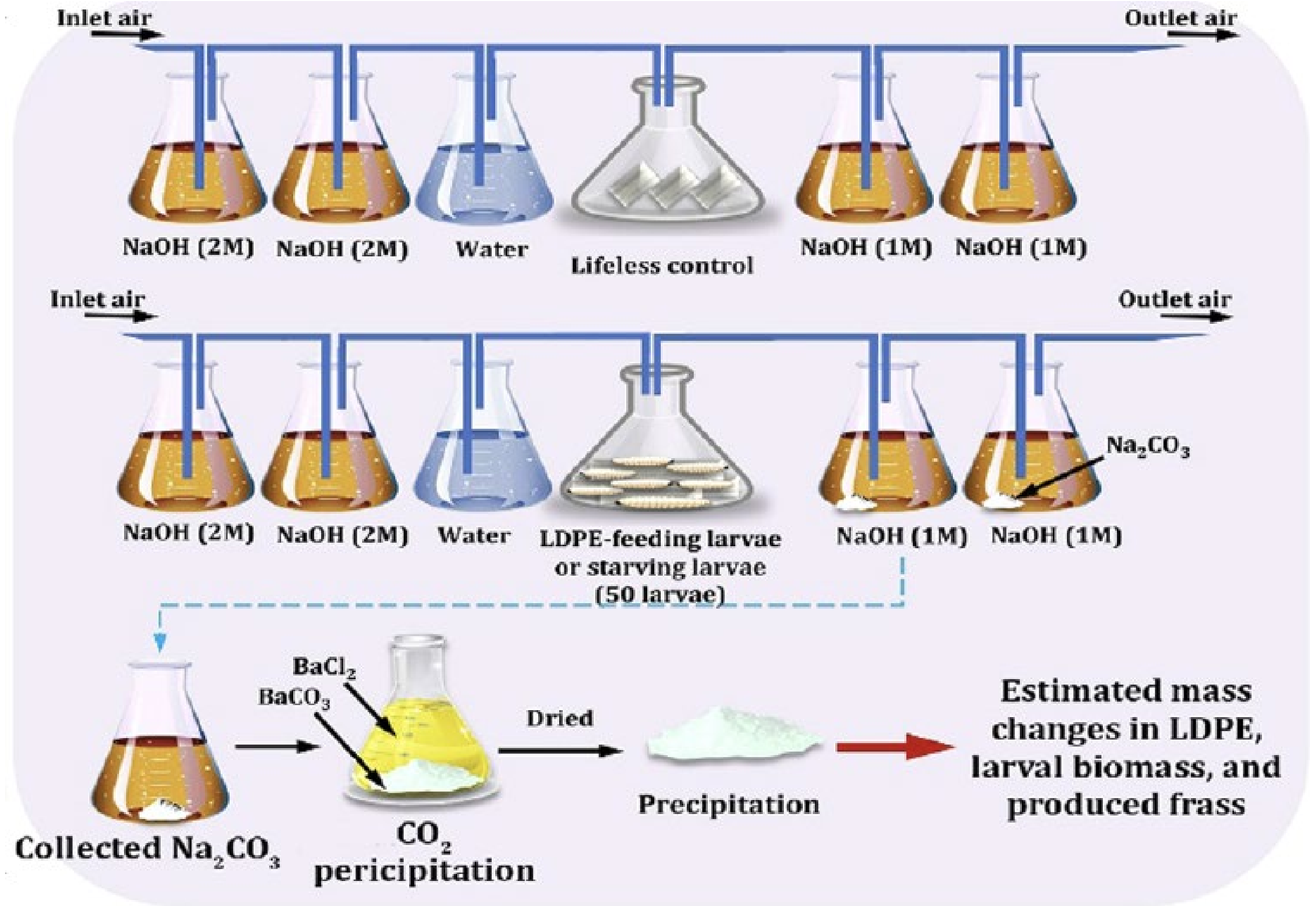


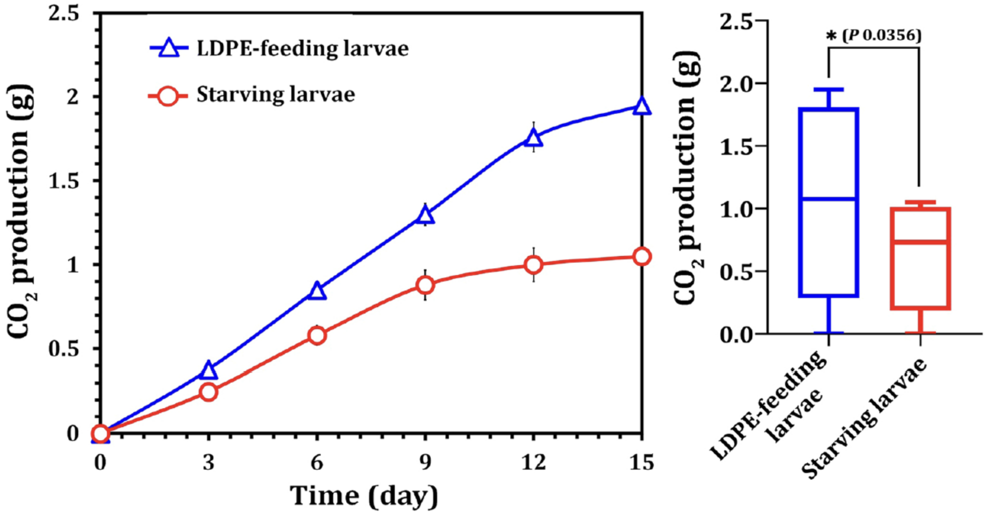
Survival rate percentage during the second generation

LDPE can support the survival and completion life cycle of waxworms as a food source

(Ali, et al., *J Hazard Mater.* 2022)

Larvae respiration test



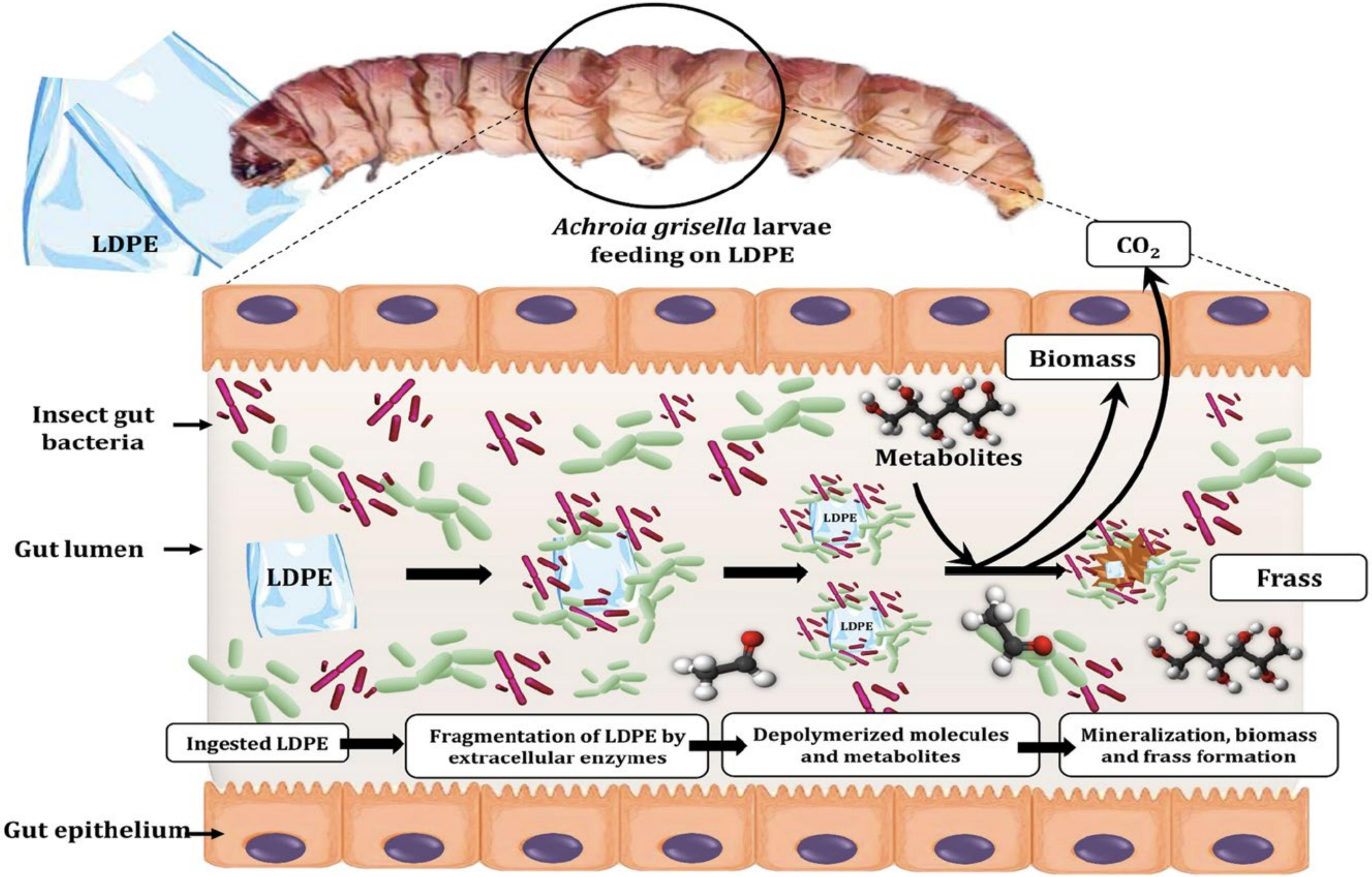


Comparison of CO2 production during the ingestion of LDPE by LDPE-feeding larvae and starving larvae

Waxworms can digest and make use of LDPE for metabolism

(Ali, et al., *J Hazard Mater.* 2022)

Gut microbes from plastic-eating worms

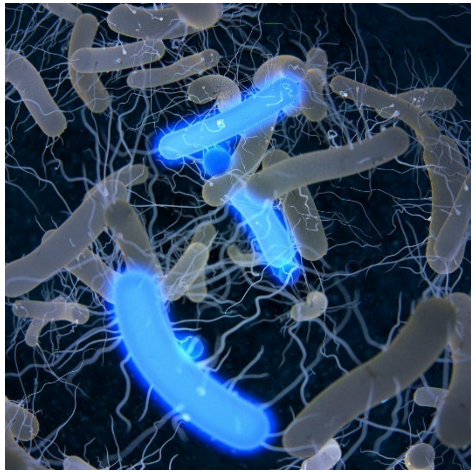


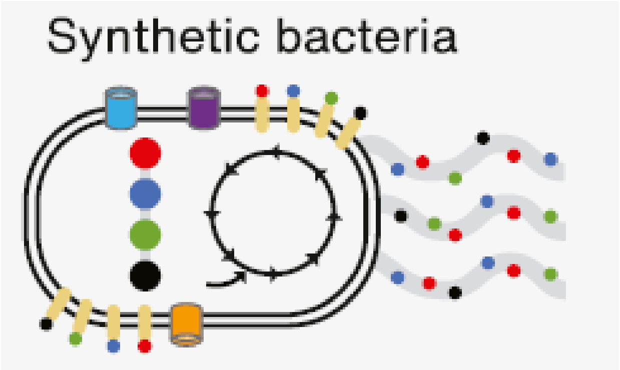
(Ali, et al., *J Hazard Mater.* 2022)

Synthetic bacteria

----Gene-edited bacteria with improved functions

- Non-natural chemical production or new functions
- New pathway design & enzyme engineering through directed evolution





- Firstly isolated from nature environment
- Grow well in harsh environments
- Efficient plastic biodegradation after genetic modifications

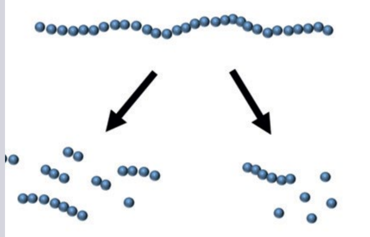
(Yeom, Le & Yun, *Trends Biotechnol.* 2022)

Steps of biodegradation

1. Biodeterioration

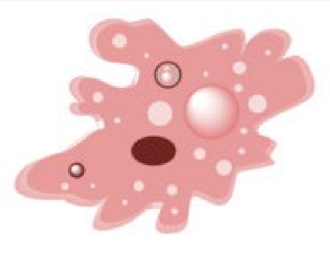
- Formation of a microbial biofilm
- Fragment material into smaller particles

2. Depolymerization



- Extracellular enzymes secretion
- Catalyze the polymer chain into oligomers, dimers, or monomers

3. Bioassimiliation



- Products uptake by microbial cells
- Production of primary and secondary metabolites

4. Mineralization

Biomass

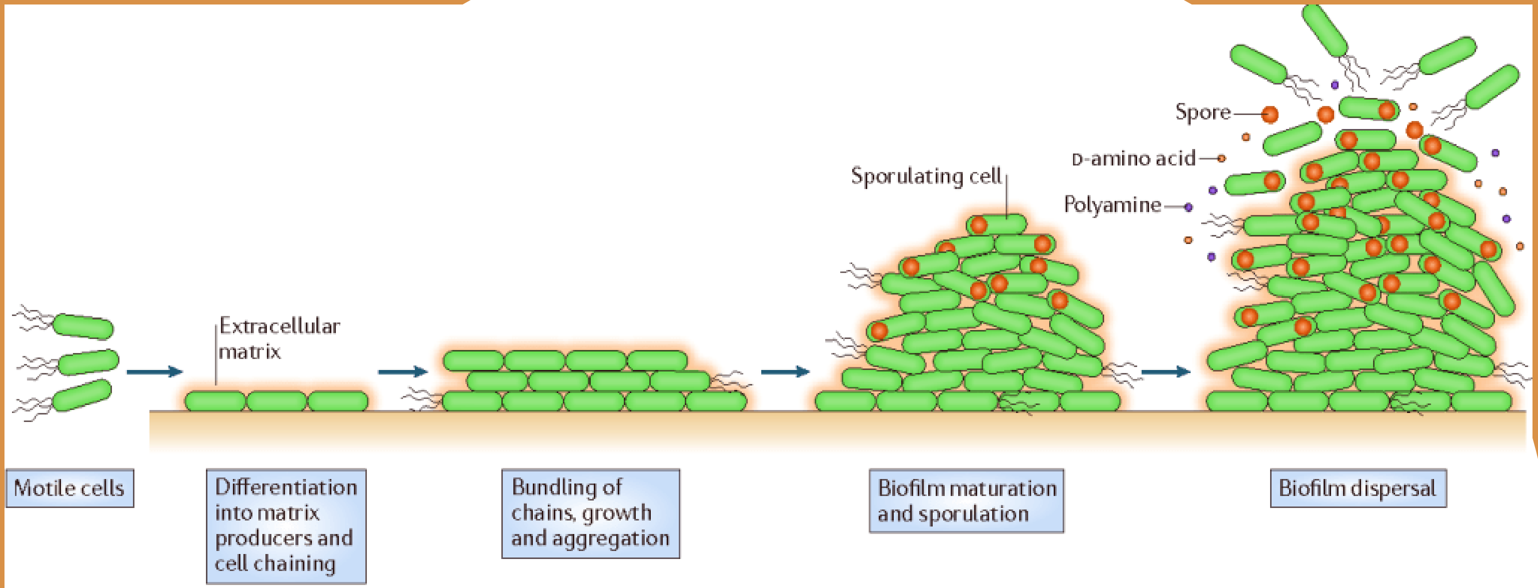
CO_2, CH_4, H_2O, N_2

- Mineralize the metabolites
- Form and release end products

(Haider, et al., *Angew Chem Int Ed Engl.* 2019)

Step 1
Biodeterioration

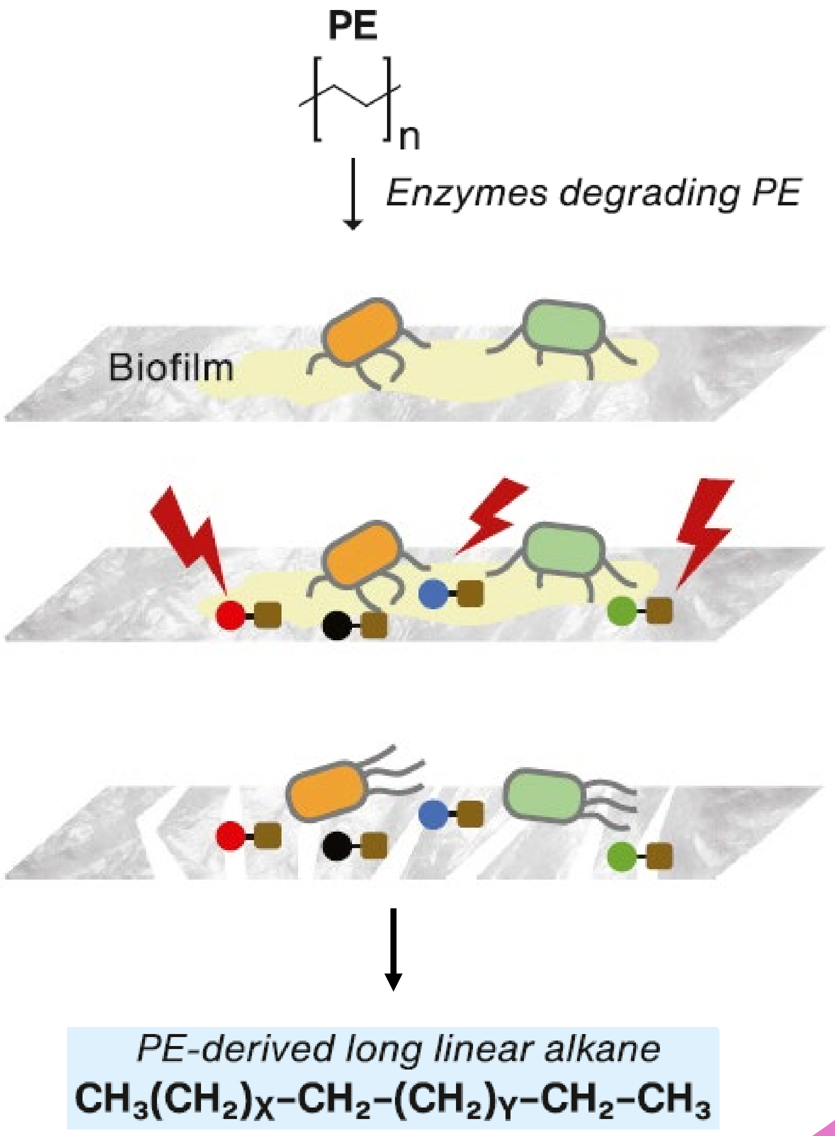
- Biofilms: Multicellular communities formed on a surface by bacteria
- Common types of plastic (e.g. polyethylene (PE) and polypropylene (PP)) have a high surface hydrophobicity
- Biofilms are necessary to increase the polymeric surface interaction with bacteria



Step 2 Depolymerization

Secretion of extracellular enzymes to break down long polymer chains

Preparation for the uptake of fragments by microbial cells

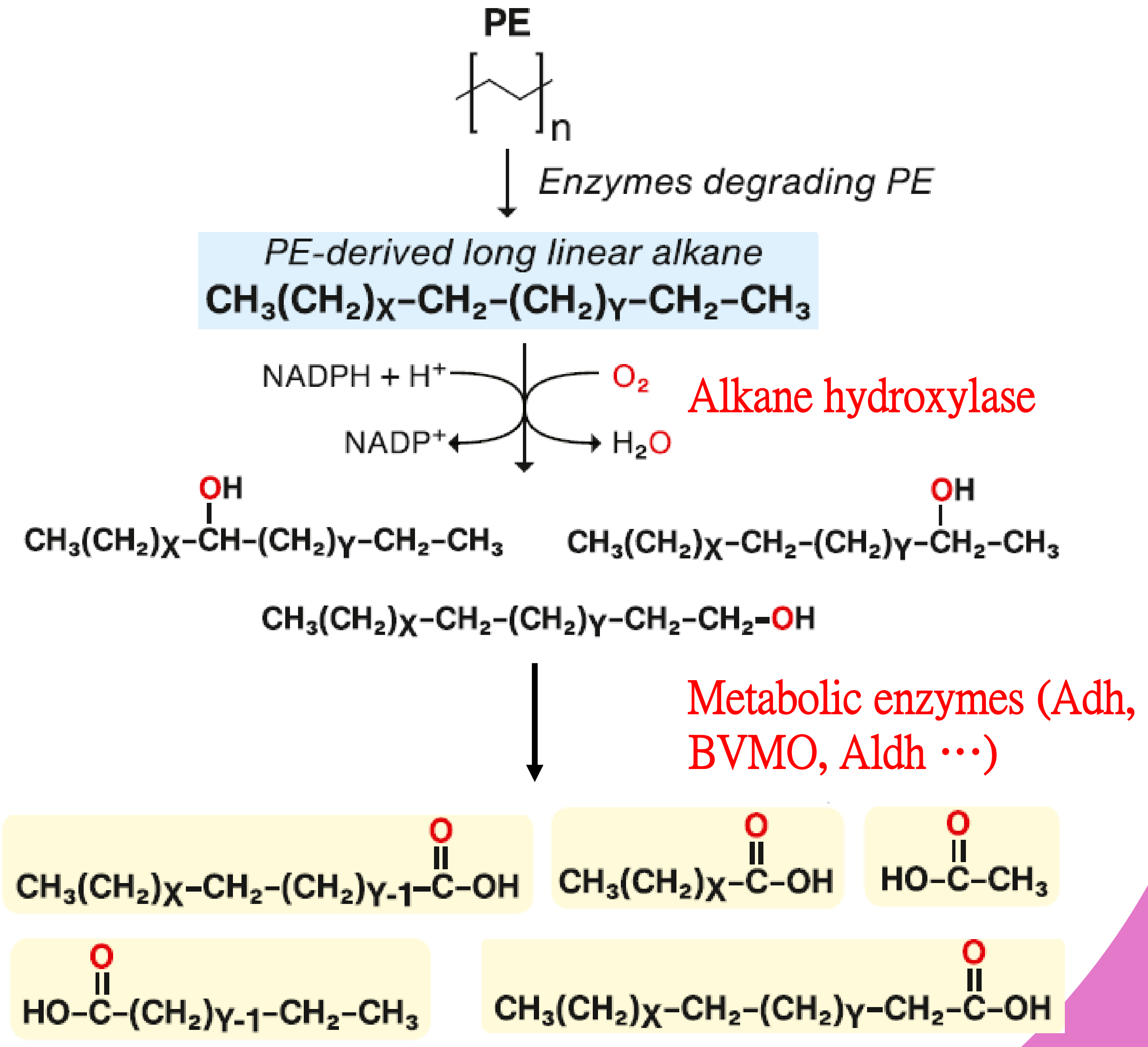


(Yeom, Le & Yun, *Trends Biotechnol.* 2022)

Step 3 Bioassimiliation

- The most important step with varieties of enzymes involved

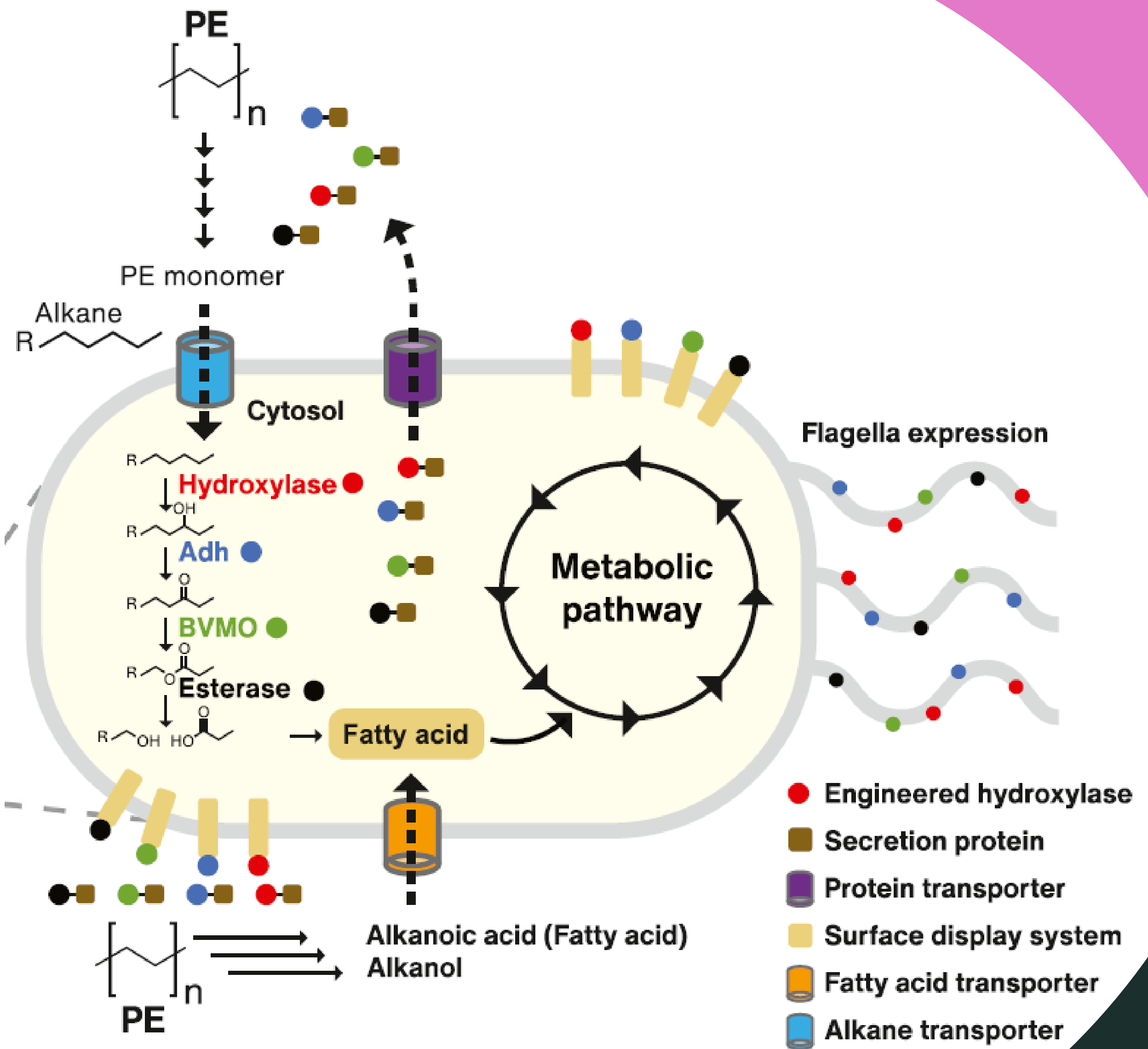
1. PE-derived long linear alkane hydroxylation
2. Formation of end products (fatty acids and acetic acid) through comprehensive biocatalysis



(Yeom, Le & Yun, *Trends Biotechnol.* 2022)

Step 2 Bioassimiliation

- Fatty acids consumed by metabolic pathway
- Take place intracellularly and extracellularly
- Transporters added to promote efficiency



(Yeom, Le & Yun, *Trends Biotechnol.* 2022)

Step 4 Mineralization

Release of the very end product after the metabolic cycle to the environment

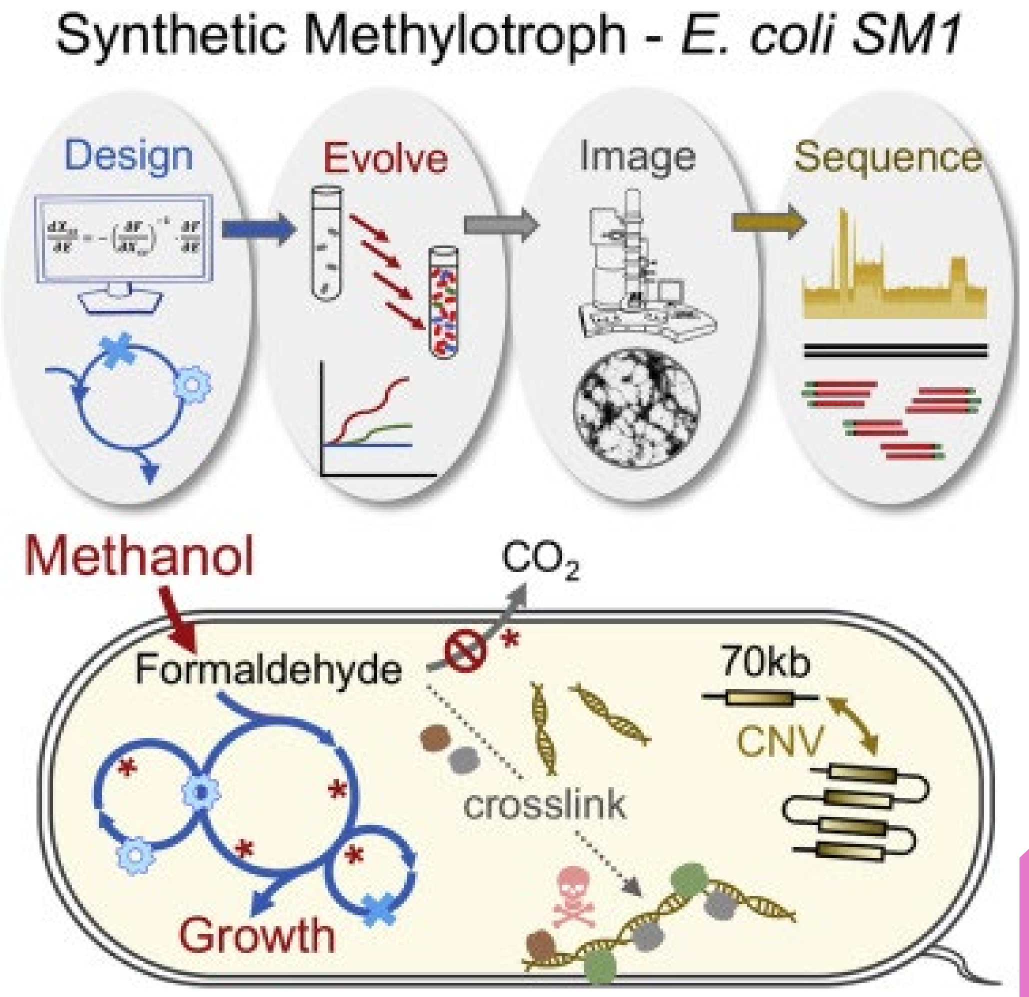
Usually harmless gases (CO_2, CH_4, H_2O, and N_2) and biomass

(Yeom, Le & Yun, *Trends Biotechnol.* 2022)

Feasibility of synthesized bacteria application

----Application of new enzymes to change carbon source

- E. coli usually cannot use methanol as a sole carbon source
- Methanol dehydrogenase and C－C bonding enzymes redesign the metabolic pathway
- The E.coli cells significantly assimilate methanol



(Chen, et al., *Cell.* 2020)

Conclusion

- Synthetic bacteria for plastic degradation requires Alkane hydroxylase, multiple catalytic enzymes, and different transporters in genetic modification.
- Plastic-degrading synthetic bacteria is feasible with theoretic support of changing carbon source

Reference

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Thank you!