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Perspective (Special Issue for Excellent Research Work in Recognition of Scientists Who Are in Catalysis Field in China)

Recent advances in new bio-catalytic systems for the production of transportation fuels and organic chemicals

Enze Min *

1. Introduction

The fluctuation in the price of petroleum-based chemicals and polymers has increased the impetus to seek alternative renewable biomass resources. The long term driving force is to provide cheaper chemicals and lower polymer prices. The short term objective, however, is to develop these alternative resources in preparation for the day when the limited petrochemical resources become scarce. The key factors in this search are the processes and catalysts [1]. The resources will be most likely based on plants with rich polysaccharide content. While the obvious choice is soft fruits, there are many crops yielding much higher saccharides than fructose. Cereal crops (e.g. corn), potato, sugar cane, and sugar beet are traditional sources of ethanol, which is also a primary source for several industrial chemicals. While fruits, cereals and root vegetables can be used for industrial purposes, facing competition from food demands.

The richest biomass resource on Earth is lignocellulose. The search for lignocellulose utilization has led to the examination of available catalyst technologies that are not necessarily based on man-made catalysts. Catalysts such as bacteria, fungi, en-

zymes and algae are now being developed specifically for target chemicals. Genetic modification is also playing a vital role in these searches. In the following, the latest developments in these catalyst systems worldwide are reviewed.

2. Bacteria

Bacteria were the first life form on Earth and are more abundant than any other living organisms. Their sizes vary between 0.5 to 5 μm . Some are visible to the naked eye and can be up to 0.30 mm in length [2]. Carbon metabolism is either heterophobic (when organic compounds are used as carbon sources) or autotrophic (when cellular carbon is obtained by reacting with carbon dioxide). Under anaerobic conditions, the bacteria uses inorganic substances such as nitrates, sulphates or CO_2 as electron acceptors. In the absence of these electron acceptors, chemotrophs make the electrons themselves.

Bacteria convert substrates to oxidized intermediates to form fermentation products such as ethanol, lactates, hydrogen and butyric acid. Fermentation takes place and as a result the energy content of the substrate is higher than that of the products. These processes interest us in the search for bacteria as

Min Enze (Senior Consultant, Research Institute of Petroleum Processing, Sinopec) **received the Catalysis Achievement Award (the Dayu Zhang Award) presented by The Catalysis Society of China in 2006.** Dr. Min received a PhD. degree from Ohio State University in 1951. Dr. Min is an academican of the Chinese Academy of Sciences and the Chinese Academy of Engineering, and a fellow of TWAS. From 1955–1965, Dr. Min participated in and supervised R&D of phosphoric acid-kieselguhr polymerization, spherical silica-alumina cracking, microspherical silica-alumina cracking and platinum reforming catalysts, which formed the basis of the catalyst plants built that laid the foundation for producing petroleum-refining catalysts in China. Since 1985, Dr. Min has supervised and directed basic and exploratory research for the innovation of new catalysts and catalytic processes. Amorphous nickel alloy, rectorite pillared clay, suspension catalytic distillation and magnetically stabilized fluidized bed were innovated and commercialized, and advanced and unique catalytic technologies were commercialized. Since 1995, Dr. Min has devoted himself to developing green processes for protecting the environment, a green process for manufacturing caprolactam, a near-supercritical process for manufacturing biodiesel and mild processes for the hydrogenation sweetening of jet fuel were developed and commercialized. Min Enze won the State Supreme Science and Technology Award for 2007.

Fig. 1. Overview of the PetroAlgae process.

Fig. 2. Flowchart of the PetroAlgae process.

catalysts for the production of the monomers of biomass-based polymers and other chemicals.

At present, the following processes have been successfully achieved: (1) production of ethylene and propylene from fermentation of polysaccharides; (2) manufacture of a mixture of acetone (30%), ethanol (10%) and butanol (60%) from fermentation of corn starch; (3) production of succinic acid using bacteria; (4) production of sucrose from glycerol, a byproduct in the manufacture of biodiesel fuel, and (5) production of butadiene from a variety of sources such as molasses, sugarcane juice, sugar, and wood waste. Furthermore, much research & development (R&D) resources are dedicated to modify bacteria to produce modified enzymes.

3. Algae

PetroAlgae, Inc. at Melburne, FL, USA was the first company to set up for developing alternative fuels and petrochemicals from algae. Algae Research Laboratory at Research Institute of Petroleum Processing (RIPP), Sinopec Corp. has also been working in this area in Beijing since 2010. PetroAlgae expects to be the first renewable energy company to achieve the commercialization of drop-in replacements of fossil fuels. The key PetroAlgae technology includes large open bioreactors, access to over 150 micro-crop strains, and the understanding and

Table 1
Biomass yield comparison.

Biomass source	Biomass yield (MT/ha/yr)
Soy	1–2.5
Rapeseed	3
Palm Oil	19
Switch grass	15
Alfalfa	3–8
Jatropha	7.5–10
Other Micro-crop Companies	2–50
PetroAlgae	80–100

Fig. 4. Soft water cultivation at Wuhan Botanic Institute.

control of growth fundamentals. The process overview is shown in Fig. 1. Fig. 2 shows the flow chart of the PetroAlgae process.

The superiority of PetroAlgae technology to other uses of biomass sources is shown in Table 1. A joint research & development program between the Chinese Academy of Sciences and Sinopec Corp. was started in 2008. Fig. 3 shows the salt water for open-pond cultivation of algae at South Sea Research Institute from the laboratory scale to a pond of 1200 m². Figs. 4 and 5 show soft water cultivation at Wuhan Botanic Institute, and the Algae Research Laboratory at RIPP, Sinopec Corp., respectively.

Fig. 5. Algae Research Laboratory at RIPP, Sinopec Corp.

Fig. 3. Open-pond cultivation of algae in salt water at South Sea Research Institute.

Graphical Abstract

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Recent progress in the characterization and application of bacteria as biocatalysts are reviewed and algae research in PetroAlgae Inc. and Algae Research Laboratory of Research Institute of Petroleum Processing Institute are discussed.

4. Conclusions

It is expected that due to the abundant supply of lignocellulose, the research and development of new bio-catalyst systems for lignocellulose fermentation will be strengthened, which will lead to new products and new enterprises.

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生产运输燃料和有机化学品生物催化体系的新进展

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摘要: 总结了细菌作为生物催化剂的特征和应用的新进展, 预测了未来发展趋势. 深入讨论了微藻系统的发展, 包括PetroAlgae公司和中国石化石油化工科学研究院微藻实验室的一些进展.