# Biological potential of microalgae in China for biorefinery-based production of biofuels and high value compounds

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**Microalgae abundance and diversity in China shows promise for identifying suitable strains for developing algal biorefinery. Numerous strains of microalgae have already been assessed as feedstocks for bioethanol and biodiesel production, but commercial scale algal biofuel production is yet to be demonstrated, most likely due to huge energy costs associated with algae cultivation, harvesting and processing. Biorefining, integrated processes for the conversion of biomass into a variety of products, can improve the prospects of microalgal biofuels by combining them with the production of high value co-products. Numerous microalgal strains in China have been identified as producers of various high value by-products with wide application in the medicine, food, and cosmetics industries. This paper reviews microalgae resources in China and their potential in producing liquid biofuels (bioethanol and biodiesel) and high value products in an integrated biorefinery approach. Implementation of a 'high value product first' principle should make the integrated process of fuels and chemicals production economically feasible and will ensure that public and private interest in the development of microalgal biotechnology is maintained.**

## Introduction

This work introduces China's biological microalgal resources Q2 which could be used for biorefinery-based production of high value products and biofuels in an integrated approach. Expansion of world population and rapid industrialisation of many countries have caused a serious depletion of fossil fuel resources. According to the latest British Petroleum (BP) Statistical Review of World Energy 2014, world oil consumption grew above 1.4 million barrels per day (b/d), from 89.931 million b/d in 2012 to 91.331 million b/d in 2013, while proven oil reserves were estimated as 1687.9 billion barrels at the end of 2013. These reserves are sufficient to meet 53.3 years of global production assuming current consumption trends [1]. These trends however are likely to change with increased fuel consumption in fast-developing Asia. In addition, greenhouse gases ($CO_2$) [2,3], noxious gases ($SO_2$, $NO_2$) [4], and PM 2.5 [5] emitted by fossil fuel combustion are the main causes of environmental problems like global warming, acid rain, and haze. These serious environmental issues produce additional indirect effects that are externalised to society with costs that are rarely accounted for. All of these issues render fossil fuels as unsustainable energy resources. Excessive dependence on fossil fuels not only brings serious environmental costs but also causes wars and conflicts because of the pressure for securing crude oil supply resulting from unbalanced global distribution of these resources. Biofuels have long been expected to at least partially relieve these problems and steadily provide energy for more sustainable development of societies worldwide.

Biofuels contain energy derived directly or indirectly from geologically recent carbon fixation in living organisms, that makes them nearly carbon neutral; they also have lower environmental impact and emission profiles than fossil fuels [6–8]. Two of the most dominant biofuels, bioethanol and biodiesel,

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are seen as substitutes for the petroleum-derived fuels, diesel and gasoline.

To date, three generations of crops have been proposed as feedstocks for biofuel production. First generation crops used for biofuel production are corn, soybean, and sugarcane – edible crops with high sugar or oil content. Second generation crops include dedicated lignocellulose crops grown on marginal lands like switchgrass, poplar, or *Miscanthus*. Third generation feedstocks are microalgae and other aquatic organisms, mostly unicellular or simple multi-cellular, that exhibit a variety of metabolisms, predominantly autotrophic but also facultative or obligate heterotrophic [9]. High growth rates reported for many microalgae [10–12] make them a promising source of biomass that could produce higher amount of biomass per hectare than most terrestrial plants can. Moreover, some microalgae species such as *Dunaliella salina* [13] are able to grow well in saline water, which makes them more promising feedstock than terrestrial crops that rely exclusively on fresh water. Despite these advantages, technical and economic bottlenecks in cultivation, harvesting, dewatering, and energy conversion efficiency are still main barriers which hinder commercialisation of algal biofuels [14]. To date, neither isolating new strains nor optimising known cultivation and harvesting techniques have been able to successfully demonstrate cost effective production of biofuels from microalgae. In order to make microalgae a viable biofuel feedstock, significant advances need to be made in cost reduction through technological breakthroughs and/or integrating multiple processes.

Biorefining, integrated processes for the conversion of biomass into a variety of products, can improve the prospects of microalgal biofuels by combining them with the production of high value co-products such as polyunsaturated fatty acids like DHA or EPA, carotenoids, antioxidants, proteins and pharmaceuticals [15,16]. The biorefinery approach will help to close the economic gap between current costs of microalgae cultivation and processing and costs of fossil fuels.

China, the world's most populated country and third largest economy after EU and US, has faced an enormous energy shortage in recent years. In 2013, China remained the largest energy consumer while its oil reserves account for 1.1% of world's reserves [1]. Releasing the potential of biofuels in China is therefore essential for maintaining its continuous development. China also suffers a shortage of arable land and freshwater resources. Therefore development of biofuels should exclusively focus on second and third generation feedstocks. This paper reviews microalgae resources in China and their potential in producing liquid biofuels (bioethanol and biodiesel) and high value products in an integrated biorefinery approach.

## Microalgae resources in China

### *Biodiversity of microalgae in China*

China's huge area, complex topography, diversity of climates, and aquatic habitats results in a great diversity of microalgae resources that can be explored. Microalgae are widely distributed in freshwater lakes, rivers, and coastal seawater. Bundles of literature have reported the abundance and distribution of microalgae in various water bodies in China, including South China Sea [17,18], Pearl River Delta [19,20], Bohai Sea [21,22], among others.

According to a survey of the phytoplankton community of central Bohai and its adjacent waters [22], approximately 432 species of phytoplankton, dominated by diatom and dinoflagellates, have been found. In the Pearl River estuary [23] there were 239 species identified, among which 72.4% belong to diatom, 23.8% to *Pyrrophyta*, and 3.8% to others. Table 1 summarises phytoplankton diversity and abundance in a typical water body

**TABLE 1**

**Phytoplankton diversity in typical water area in China.**

| Area | Number of phytoplankton species | Reported highest abundance | Normalised abundance ($\times 10^3$ cells/L) | Dominant species | Reference |
|---|---|---|---|---|---|
| **Changjiang estuary** | 208 | $1277.88 \times 10^3$ cells/dm$^3$ | 1277.88 | *Chaetoceros*, *Coscinodiscus*, *Thalassiosira* | [84] |
| **Pearl river** | 239 | $2.767.1 \times 10^4$ cells/m$^3$ | 27 | *Thalassiothrix, frauenfeldii, Nitzschia delicatissima*<br>*Thalassiosira subtilis* | [23] |
| **Yellow river** | 114 | $303.35 \times 10^4$ cells/m$^3$ | 3.03 | Bacillariophyta, Chlorophyta | [85] |
| **Bohai** | 432 | $535.45 \times 10^4$ cells/m$^3$ | 5.3 | Coscinodiscus, Excentricus, Ceratium fusus | [22] |
| **South China Sea** | 150 | *Summer:* $6001.78 \times 10^3$ cells/dm$^3$<br>*Winter:* $37.52 \times 10^3$ cells/dm$^3$ | *Summer:* 6001.78<br>*Winter:* 37.52 | *Trichodesmium thiebautii, Thalassionema nitzschioides*<br>*Pseudo-nitzschia delicatissima, Gymnodinium* spp.<br>*Thalassionemafrauenfeldii, Chaetoceros messanensis* | [86] |
| **East China Sea** | 144 | $1158.6 \times 10^3$ cells/dm$^3$ | 1158.6 | Bacillariophyta, Pyrrophyta | [87] |
| **Yellow Sea** | 379 | *Summer:* $4137.1 \times 10^3$ cells/m$^3$<br>*Spring:* $3940.4 \times 10^3$ cells/m$^3$<br>*Winter:* $3010.6 \times 10^3$ cells/m$^3$<br>*Autumn:* $340.8 \times 10^3$ cells/m$^3$ | *Summer:* 4.137<br>*Spring:* 3.940<br>*Winter:* 3.010<br>*Autumn:* 0.34 | Spring: *Thalassiosira pacifica, Skeletoema* spp., *Chaetoceros cinctus*<br>Summer: *Chaetoceros debbilis, Chaetoceros pseudocurvisetus, Chaetoceros curvisetus*<br>Autumn: *Thalassiosira curviseriata, Alexandrium catenella, Ceratium fusus*<br>Winter: *Paralia sulcata, Phaeocystis* sp., *Bacillaria paradoxa* | [88] |



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