Nanoparticle Technology for Biorefinery of Non–Food Source Feedstocks

Development of Microalgae-produced Biofuels Utilizing Mesoporous Nanoparticle Catalysts

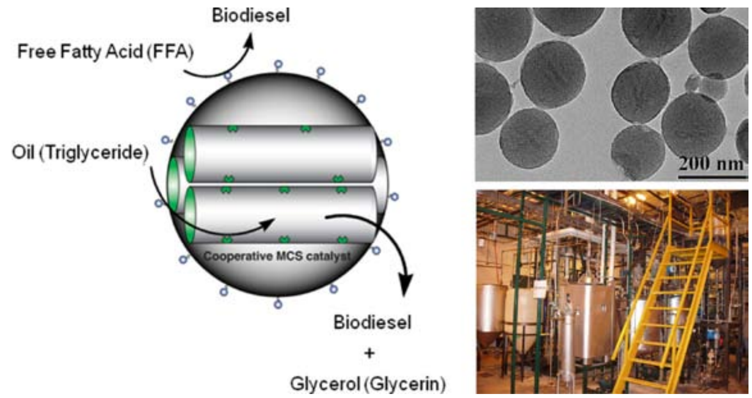

Figure 1. Left: Mesoporous nanoparticle catalyst for biodiesel production. Upper right: Transmission electron microscope image of mesoporous silica nanoparticles sample. Lower right: The pilot plant for nanoparticle-catalyzed production of biodiesel.

Illustration and images courtesy of Iowa State University.

Recent high petroleum prices and the desire for increased energy independence and security have led to the rapid development of a variety of alternative fuels. Among these fuels, biodiesel is a biodegradable, nontoxic diesel produced from various oil feedstocks, including vegetable oils, animal fats, microalgae, and restaurant waste oils. In the United States, oils extracted from soybeans have been the primary source of biodiesel. However, the use of a crop-based feedstock such as soybeans has inherent limitations, such as a limited cultivation area and potential negative impacts on the food source market. Additionally, soybeans offer a lower yield of oil per hectare than microalgae (which have an estimated yield 500 times that of soybeans).

A more appropriate feedstock for biodiesel production would utilize nonfood sources, such as waste animal fat, waste biomass, or microalgae. However, the potential for employing microalgae-derived oil as a source for biodiesel is currently limited by the cost and technical complexity associated with the cultivation of the microalgae, the extraction and refining of the oil, and its conversion into biodiesel.

To overcome these obstacles, this project is utilizing already developed mesoporous nanoparticle materials to develop microalgae-produced biodiesel fuel. The laboratory and pilot-plant scale application of this nanoparticle-based catalytic technology has already produced biodiesel that meets ASTM International standards. This project is scaling up the synthesis of the nanomaterials from the pilot-plant scale to an industrial level.

Benefits for Our Industry and Our Nation

This project has the potential to reduce energy on many levels, including energy gathering, energy production, and energy consumption (fuel transportation and distribution). The environmental benefits of biodiesel over petroleum-based diesel fuel include lower emissions of unburned hydrocarbons and particulate matter. Biodiesel also contributes no net carbon dioxide or sulfur to the atmosphere. Further, this nanomaterials synthesis method utilizes reusable, multifunctional, and highly reactive nanoparticles that require no water washings, which will save large quantities of water as compared to conventional biodiesel synthesis methods.

Applications in Our Nation's Industry

Application of this synthesis method will have a direct impact on the biodiesel production industry, and consequently, the energy and fuel industries as well. The direct market segments of biodiesel production include electrical generation, farming, fleets, bioheat fuel, marine, mining, passenger vehicles, premium diesel, school buses, and transit.

Project Description

The specific goals of this project are as follows: (1) to selectively isolate fuel-relevant hydrocarbons from live microalgae by using mesoporous material, (2) to convert microalgae-based hydrocarbons and waste oils to biodiesel in a single step using a mesoporous mixed metal-oxide catalyst, and (3) to develop this research to the point of commercialization in 3 to 5 years.

Barriers

- Identification and large-scale production of nanoparticles with optimal properties for large-scale oil extraction and production
- Establishment of the optimal cultivation conditions for the most productive algae
- Ensuring that overall production costs are kept low

Pathways

Recently, structurally ordered nanoparticles have attracted attention because of their tailored porosity and surface chemistry; high specific surface area; large pore volume; and high thermal, chemical, and mechanical stabilities. For example, ordered mesoporous catalytic solid (MCS) nanoparticles can be used as a heterogeneous catalyst to enable cleaner biodiesel production as compared to traditional transesterification processes. The MCS approach has proven to speed up the reaction, require less thermal input, use less water, and be easily recovered and reused.

Mesoporous catalytic solid nanoparticles are already being produced at the pilot-plant scale, while other promising nanoparticle catalysts are produced at the laboratory scale. This project will gradually increase the batch sizes of these nanoparticle materials to reach a commercial scale.

This project will also increase the extraction efficiency of fuel-relevant hydrocarbons from feedstock and the establishment of extraction conditions appropriate for a large oil-production scale. The biodiesel production process will be scaled up from the existing pilot plant scale. Nanomaterial properties will be continuously improved upon and tailored based on feedback from the scaling up processes.

Milestones

This project started in September 2008.

- Scale-up of the syntheses of the nanoparticle materials, determination of optimal synthesis conditions, and establishment of the optimal batch size based on the results of a series of different reaction volumes. Mesoporous Calcia Silicate (MCS) is being produced at pilot plant scale, while Mesoporous Silica Nanoparticles (MSN) and Mesoporous Carbon Nanoparticles (MCN) are produced at laboratory scale. The batch size of the three materials is currently being increased up to a commercial scale. (Completed)
- Scale-up of oil extraction and establishment of the optimal cultivation and oil-extraction conditions. The volume of oil extracted is being increased to large production scale by the selection and optimization of feedstock properties and adequate extraction conditions. (Completed)
- Scale-up of the biodiesel production processes in a way that ensures optimal dispersion homogeneity and temperature settings. Pilot plant scale has already been achieved for this process. Larger scaling is currently under development. (Completed)

Commercialization

Catilin Inc. has secured a pilot-scale biodiesel plant (1 million gallons per year) that is being converted from a batch-treatment plant for traditional biodiesel production to a continuous-flow plant that will utilize the solid nanoparticle catalyst. Catilin has sinced merged with Albemarle Corporation. Research and biofuel development is continuing under the AlbemarleCatilin subsidiary of Albemarle. The merged company is leveraging relationships with several leading biodiesel engineering firms and working to identify the needs of end users.

Project Partners

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