Greening the Design of Chemical Microbial Production

12/30/11

Blue Marble Biomaterials LLC

Contact Person:

James Stephens, Chief Science Officer
Blue Marble Biomaterials
5653 Alloy South
Missoula, MT 59808
(206) 999-1802
james.stephens@bluemarblebio.com

Project Title:

Greening the Design of Chemical Microbial Production

Most recent milestone: Blue Marble scaled from pilot facility to commercial plant in 2010. The facility was planned and retrofitted in existing building and is currently undergoing food grade and kosher certification.

Award eligibility: The nominated technology is eligible for the small business award.

Focus area: This project is focused on the use of greener reaction conditions.

U.S. component: The research, development, and commercialization phases have all taken place in the United States. The company has a relationship with University of Montana, which develops students' skills in manufacturing and fabrication.

Abstract:

The majority of fine chemicals are produced from chemical synthesis using energy-intensive processes and fossil-based materials. Over the past few years, biosynthesis pathways to produce fine chemicals from biobased feedstocks have demonstrated feasibility and promise. Blue Marble Biomaterials is advancing the field of microbial fine chemical production by developing new systems that lower the carbon-intensity and improve the life cycle sustainability of such operations.

Blue Marble Biomaterials owes these advances to their unique application of polyculture fermentation, which uses no genetically modified organisms. Blue Marble's proprietary combination of microbes creates an ecosystem where a wide variety of fine chemicals and chemical intermediaries are produced in a single batch, including: carboxylic acids, esters, thiols, and other organosulfur compounds. The polyculture system is feedstock-agnostic and resistant to environmental stress, and thus is able to process non-sterile lignin, cellulose, and protein-based feedstocks with no chemical or thermal pre-processing. Due to these unique characteristics, Blue Marble uses low-cost byproduct streams of food, forestry, and algae companies. The utilization of these feedstocks directly prevents the landfilling or burning of these materials, abating approximately 15.28 tons of Carbon Dioxide Equivalent for each ton of feedstock used. In comparison to microbial production systems that require virgin or pre-processed plant materials, which are carbon and energy-intensive, Blue Marble's system recycles available biomass to abate the release of greenhouse gas emissions.

In 2010 the company scaled production from a pilot facility to a commercial facility in Missoula, Montana. The commercial facility will operate at 100% capacity in Q1 2012. It will intake 860 wet tons of feedstock per year and annually produce 414,900 kilograms of carboxylic acids, esters, thiols, and other organosulfur compounds. An on-site water recycling system reuses 75% of the water required for fermentation, saving a total of 574,000 gallons of water per month. Additionally, all biogas from the fermentation system runs through an algae remediation system which scrubs CO2 and methane to reduce facility emissions.

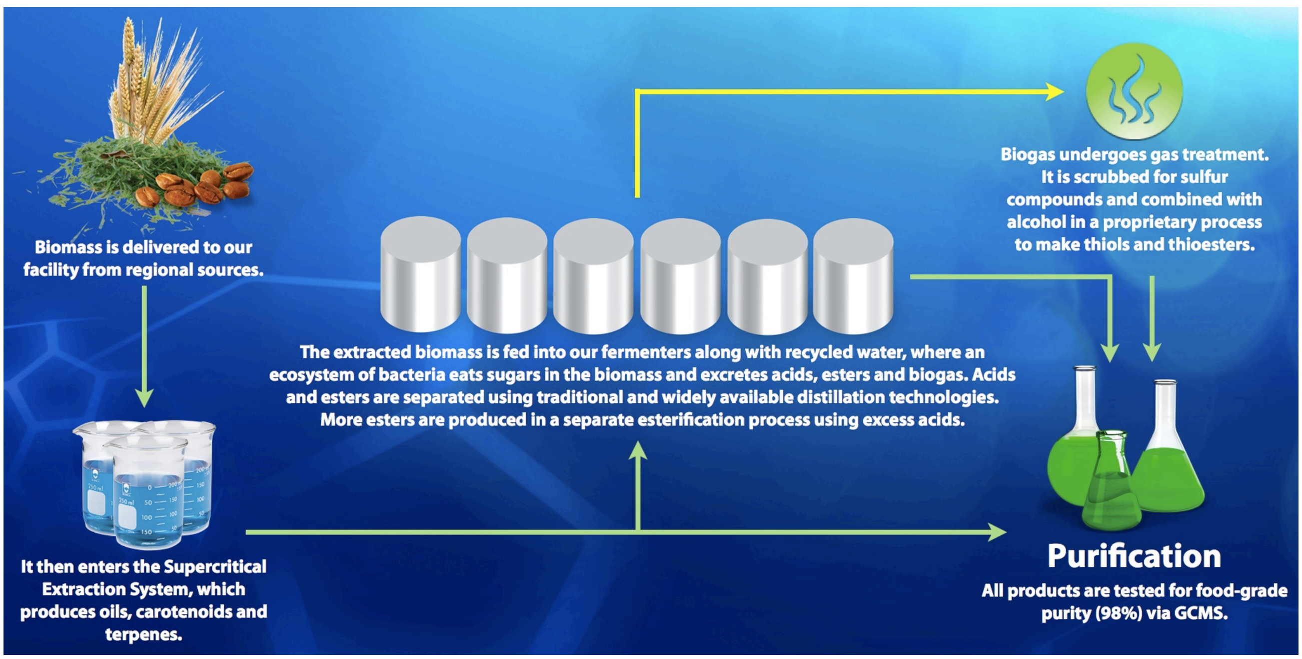
Blue Marble is engaged with several major manufacturers in the flavoring, food, and personal care industries (names available under NDA). The company also has a memorandum of understanding with Sigma-Aldrich Fine Chemicals to work towards global distribution of seven compounds.

Additional Information

I. Technology Overview

The focus of this project is how our process makes microbial fermentation more cost-effective and more sustainable over the lifecycle of production. However, Blue Marble uses a total of three key technologies to produce its portfolio of compounds: supercritical and subcritical extraction*, multi-stage fermentation, and gas treatment*. Figure 1 below demonstrates how these technologies are linked together in our process.

Figure 1: Process Overview



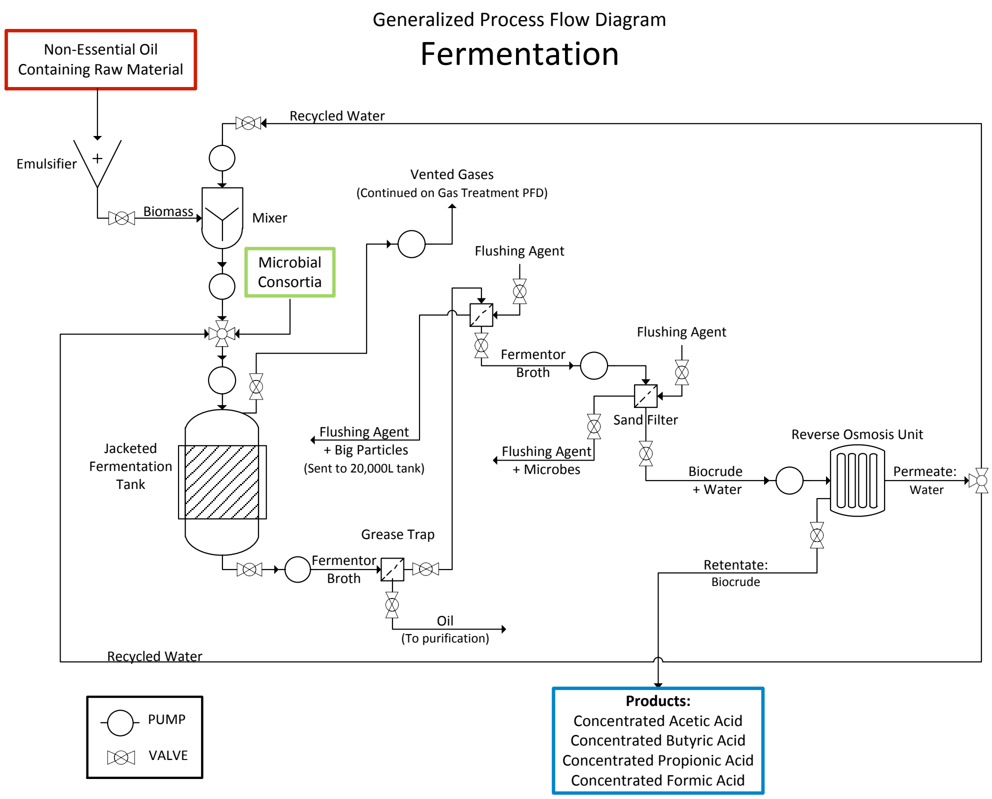
a. Fermentation Process & Biochemistry

The fermentation process is fueled by our unique polyculture microbial consortia, the leaps forward in cost-effectiveness and lifecycle sustainability are owed to this unique aspect of our technology. The microbial consortia that Blue Marble uses were taken from natural environments and bred to encourage consumption and production of specific compounds. The consortia are treated as a trade secret, much like the recipe to Coca-Cola, because of the unique

* Due to recent patent filings on the supercritical extraction system and the gas treatment system, Blue Marble is unable to share more information on these processes at this time. For more information, please speak to the project lead (James Stephens).

biochemical environment that it creates in the fermenters.[1] The environment is unique in two ways. First, it allows Blue Marble to control the pH of the system by extracting pH inhibitors. Second, methanogenic bacteria cannot survive past the first stage of our fermentation process. These characteristics allow Blue Marble to access a variety of waste biomass feedstocks that do not have to be pre-processed or sterilized.

Figure 2: Fermentation Process Flow Diagram



II. Solutions and Applications

Currently, the majority all industrial and fine chemicals are produced using chemical synthesis and non-renewable or fossil-based resources. 90% of all organic chemicals are derived from 7 petrochemical base molecules, with further synthesis requiring other fossil resources such as nitrogen from natural gas. Chemical production is the second largest energy consumer, accounting for 3 million barrels of oil a day, or 25% of all energy use worldwide. In the coming years, the chemical industry will acutely feel the shocks of volatile oil prices and increased pressure for cleaner technologies. Blue Marble's system is not only reducing the dependence on petroleum for chemical production using microbial chemical production, but also is advancing

1 Blue Marble is unable to provide a written biochemical pathway for production due to the sensitivity of our trade secret. However, more detail is be available via phone with the project lead.

the field for more sustainable microbial production through new biochemical pathways that lead to more sustainable feedstock options and lower capital expenses.

Leading companies that use microbial production of chemicals rely on genetically modified organisms (GMO) to conduct the fermentation process. While there is no inherent issue with this method, it adds financial and environmental costs in two ways that Blue Marble's technology addresses. First, it is widely known that developing GMOs is costly and time consuming, thus the barrier to entry and the costs to maintain such cultures is very high. Second, GMO-based fermentation requires specific feedstock inputs that must be pure and pre-processed, often times these cultures can only yield a single compound. Not only does the need to pre-process sugars and biomass increase the energy and carbon footprint of renewable chemical operations, it raises the cost of production. Blue Marble's polyculture system has cut out the need to pre-process biomass. Furthermore, Blue Marble's ability to handle multiple types of feedstocks using the same basic polyculture consortium, production tanks can be easily transferred to adjust to the new lowest-cost biomass feedstock. This ensures that no matter what the market volatility for corn, beet, sugar, or other feedstocks, our technology can adjust to process the lowest-cost feedstock quickly.

Blue Marble's production method is currently targeted towards producing high-value chemicals for the food and personal care industry. These markets are a beachhead market that will provide revenue to allow us to scale to high-volume facilities that produce industrial-grade products such as acids, esters, and oils for use as solvents, intermediaries, or fuel-additives. In our beachhead markets, Blue Marble has gained significant interest from Sigma-Aldrich in addition to two international flavoring houses (names available under NDA), as demonstrated by signed memoranda of understanding. The upstream market, known as flavors and fragrances, that Blue Marble is selling into places a premium on natural and sustainable chemicals, as consumers are increasingly attuned to ingredient lists. This has created a shortage of natural chemicals in the market. Furthermore, demand for flavors and fragrances in the U.S. alone is forecast to grow 3.7 percent per year to $5.3 billion in 2012. Given the market conditions, Blue Marble is poised to take advantage of market needs and growth with this new low-cost technology. Figure 3 shows the compounds that comprise our initial offering to these markets. This offering reflects a small percentage of our production capabilities.

Figure 3: Current Offering

Compound	Applications	CAS #
Propyl butyrate	Pineapple flavor	105-66-8
Ethyl butyrate	Orange, tutti fruity flavor	105-54-4
Propyl thioacetate	Onion, garlic flavor	2307-10-0
Ethyl thioacetate	Onion, savory flavor	625-60-5
Ethyl thiopropionate	Alliaceous flavor	2432-42-0
S-Methyl thioacetate	Cheese, dairy flavor	1534-08-3
Methyl thiobutyrate	Cheese, dairy flavor	27798-35-2
Propanethiol	Onion	107-03-9
Ammonium sulfide	Ingredient for onion / garlic flavoring	12135-76-1

III. Lifecycle Analysis

As pictured in Figure 4, our unique feedstock procurement practices create an environmental benefit in upstream and downstream markets. We benefit to feedstock providers while creating a better pathway to chemicals. This section will discuss our benefits and challenges of how we do this work

a. Feedstocks

Feedstocks are Blue Marble's main source of environmental advantage over other chemical manufacturers that use microbial production. Blue Marble exclusively uses byproduct streams from food, forestry, and algae producers. These are biomass products that would otherwise end up in a landfill or a burn pile. We are both extending the productive life of the biomass and capturing carbon through chemical production. The energy use and carbon output of the Blue Marble feedstock system is much less than virgin crops and/or extensive pre-processing.

Blue Marble is planning to co-locate several small regional facilities for chemical processing with feedstock providers. Thus transportation of feedstocks will be a matter of moving across a stockyard, rather than having to build a transportation network which would increase the impact of feedstock procurement.

b. Manufacturing

The largest challenge we will face in our facility will be the large energy use that distillation requires, as with any chemical company. However, the manufacturing process in our commercial facility is designed to reduce resource use and reprocess all waste through water recycling, emissions reduction, and waste reduction. Water is an important resource for fermentation processes as the incoming biomass is mixed to create a 90% water slurry. Thus, Blue Marble has placed an emphasis on water recycling in our facility. We use an off-the-shelf reverse osmosis system that recycles 75% of the water necessary for our facility, saving 574,000 gallons of water per month.

Blue Marble is developing an algae-based emissions reduction system that sinks CO2 and CH4 from our biogas into algae growth. In conjunction with our partners, the University of Montana and Bionavitas, Blue Marble is utilizing photobioreators and natural algae strains to which intake carbon from our biogas stream.

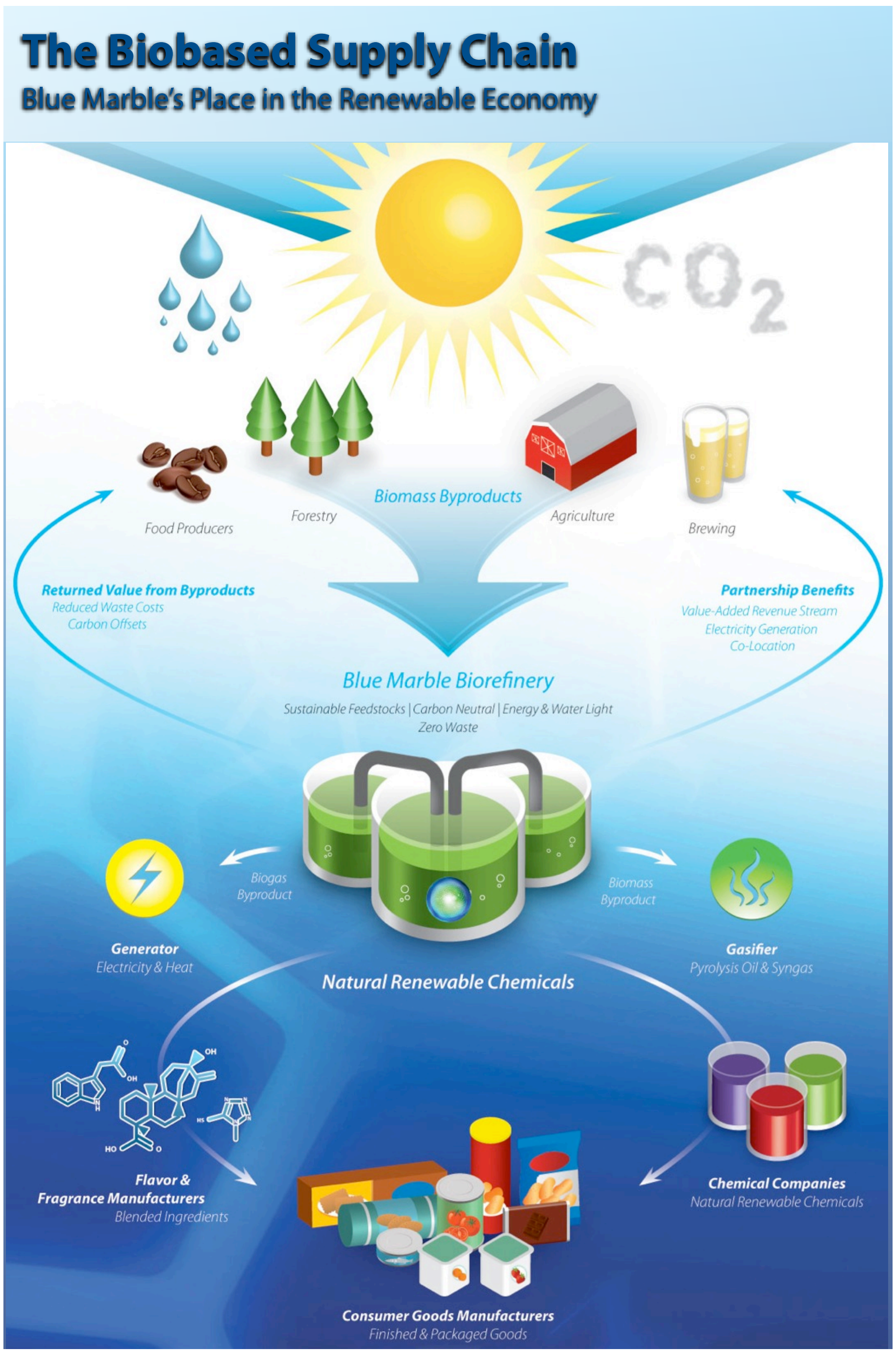
Lastly, the nitrogen-rich waste slurry that results from our fermentation process is utilized in a gasification and pyrolysis unit to produce oils and other materials that are under testing for productive use. Our mission is to turn our "waste" streams into as many productive materials as possible.

In terms of chemical reagent use and disposal, Blue Marble will maximize its use of non-toxic, non-hazardous materials. Currently none of our chemical processes require the use of such materials, because we are catalyzing reactions with only heat and pressure.

c. In-Use and End-Of-Life

Blue Marble produces no environmentally persistent chemicals in our process, thus there are no end-of-life considerations that need to be made. Each of the chemicals will break down to basic elements. Because all of our offered compounds are GRAS by the FDA, we assume that they also pose no health threats when used as recommended. The use of our chemicals in foods and personal care products will be limited to low concentrations. Most compounds we produce will be limited to approximately 5 parts per million of a finished product. In the special case of ammonium sulfide, which can degrade into hydrogen sulfide, customers (manufacturers) will need to be aware of health risks, but should ultimately pose no risk if handled and applied appropriately.

Figure 4: Blue Marble in the Biobased Economy



IV. Selection Criteria

Given the technological advance that Blue Marble has made in the microbial production of chemicals we believe we meet the following criteria for selection.

1. **Science and innovation**
    - Blue Marble is using an original application of polyculture fermentation. We are the only renewable chemical company using this method for production.
    - The mechanism for production has been proven in the pilot phase of production, which concluded in 2010. Since the commercial facility was completed in 2011, further investment and partnerships add validity to the solid science behind our process.
2. **Human health and environmental benefits**
    - This process improves the use of natural resources not only by substituting renewable feedstocks for petrochemical feedstocks, but also by improving the efficiency of renewable feedstocks through lowering the cost of production and lowering environmental impact of feedstock procurement.
3. **Applicability and impact**
    - Blue Marble's advance lowers the cost of production for microbial chemical production by eliminating the need for pre-processing biomass.
    - The acids, esters, and biogas produced from our fermentation process have a wide variety of applications beyond the flavoring and fragrance industry. Low-grade products that we produce can be used for solvents, chemical intermediaries, or fuel additives.