Special Report: Spirulina Part 7

Understanding the role of microscopic algae, the foundation of life, can help us develop restorative models of personal and planetary health. Algae are an essential part of Earth's self-regulating life support system. Innovative schemes and dreams...

Filed under Special Report: Spirulina · Tagged with algae cultivation, algae foods, Algal Biofuels, International Algae Competition, microfarming, Spirulina

Special Report: Spirulina Part 6

In over 40 countries, tablets, powder and capsules are widely used supplements. Spirulina is a featured ingredient in pasta, cookies, snack bars and juice drinks, and in personal care products like skin creams and shampoos...

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Special Report: Spirulina Part 5 Development of a Spirulina Industry – Production

Over the past 30 years, the spirulina industry has been supplied by many small to large-scale farms around the world, using a wide range of algae...

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Special Report: Spirulina Part 4 Scientific Research Reveals Health Benefits

An international detective hunt has been underway for 40 years. Researchers in Japan, China, India, Europe, USA and other countries are discovering how...

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Special Report: Spirulina Part 3 An Impressive Nutritional Profile

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Special Report: Spirulina Part 1 Origins and Biology

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Filed under Special Report: Spirulina · Tagged with Earthrise Farms, Robert Henrikson, Spirulina

The Future of Spirulina in an Evolving World

June 1, 2017, by Robert Henrikson

AlgaeIndustryMagazine.com

Understanding the role of microscopic algae, the foundation of life, can help us develop restorative models of personal and planetary health. Algae are an essential part of Earth's self-regulating life support system. Innovative schemes and dreams using algae promise to help re-green the desert, re-fertilize depleted soils, farm the oceans and encourage biodiversity. Coming soon is a significant lowering of production costs, leading to a wide variety of algae products.

Big investments in algae biofuel will grow our future food and its own bio-packaging

Algae Food and its own bio-packaging

Today, algae has been called the 'biofuel of the future.' Over 30 years ago, spirulina was called the 'food of the future'. But until now, production costs have remained high due to a combination of these factors: using agricultural land, fresh water, clean nutrients, skilled personnel, servicing big investments for pond systems, harvesting and drying infrastructure, and complying with food and quality regulations. With production costs over $10 per kilo, growing algae is still ten times the cost of many commercial foods and feeds.

Annual world microalgae output may have reached 10,000 tons of spirulina, chlorella, dunaliella and hematococcus, though even big commercial algae farms are relatively small compared to traditional farms, at less than 100 hectares in size.

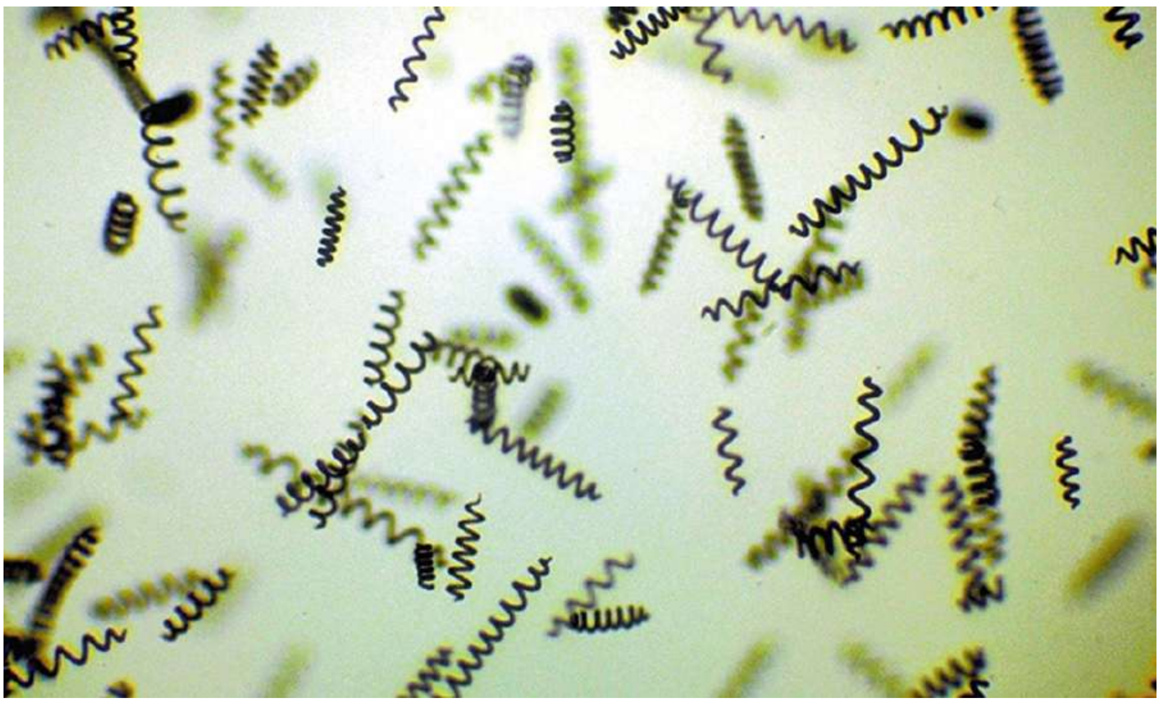
Nevertheless, the number and variety of high value food and specialty products from algae has flourished. Today, algae is an ingredient in thousands of products for food, feed, colors, nutraceuticals, medicinals, cosmetics and personal care, biofertilizers and fine chemicals.

Algae are in more products today than you know

1. Spirulina Origins and Biology

Rediscovery of a 3.5 billion year old immortal lifeform

Spirulina is the immortal descendent of the first photosynthetic life form. Beginning 3.5 billion years ago, blue-green algae created our oxygen atmosphere so other life could evolve. Since then, algae have helped regulate our planet's biosphere. Algae are two-thirds of the Earth's biomass. Thousands of algal species covering the Earth are being identified and developed for foods, feeds, pharmaceuticals, biochemicals, fertilizers and biofuels.



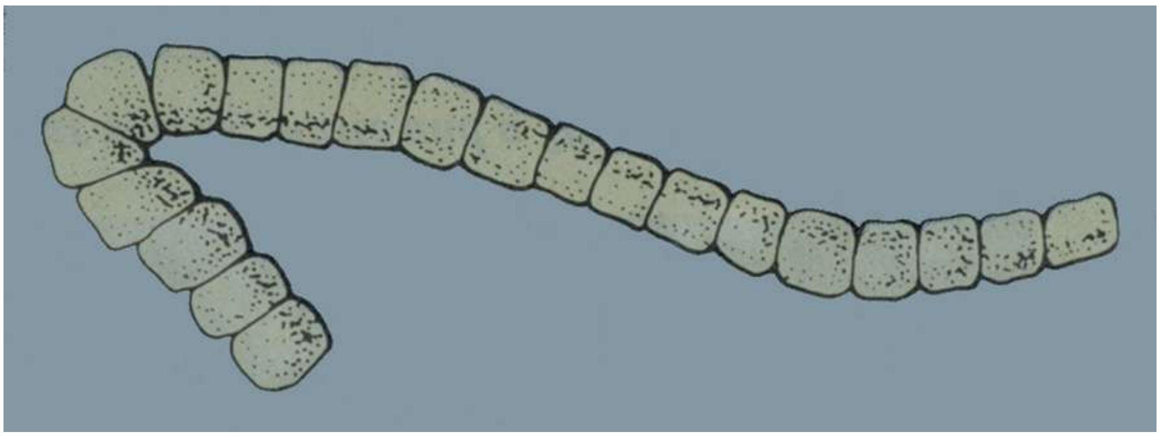
Spiral filaments under the microscope.

In the beginning were blue-green algae

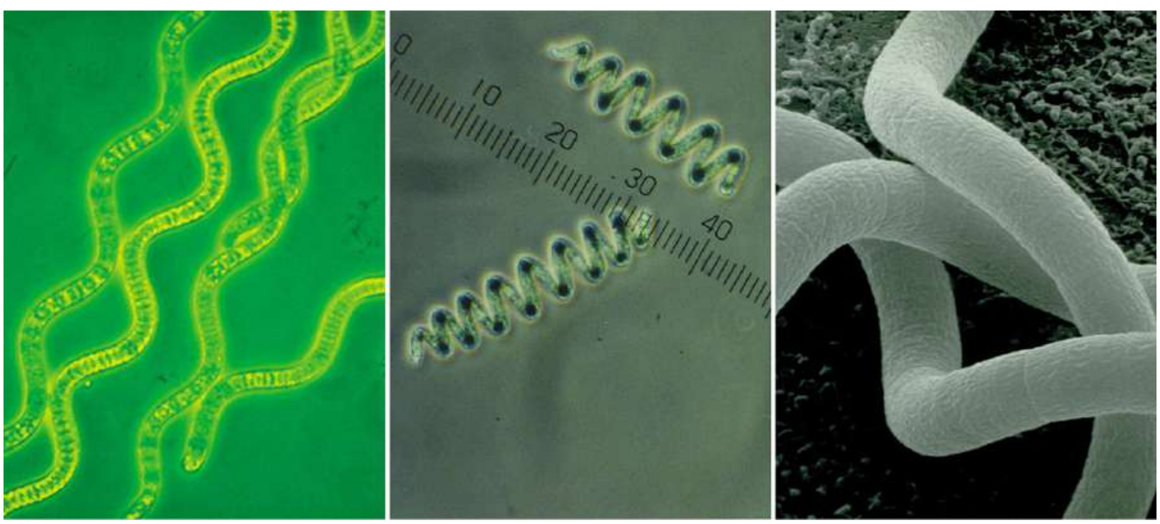
When life began on Earth, the carbon dioxide level in our atmosphere was probably 100 times greater than it is today. Life began in a greenhouse atmosphere, and microalgae played the central role in transforming this inhospitable planet into the beauty and richness that makes up life today. How this occurred is particularly relevant in view of our concern with global warming.

Scientists believe the Earth formed about 4.5 billion years ago, and the first life forms appeared 3.6 billion years ago. There is some controversy about how life was actually created on this planet. Because the young sun was 25% cooler at the beginning of life, the greenhouse effect kept a cooler planet warmer. Earth's nitrogen atmosphere, without any oxygen, was rich in greenhouse gases (like carbon dioxide and methane) absorbing and trapping radiant heat, with the infrared radiation rising from the surface. The oceans were filled with iron, sulfur and other compounds in solution because there was no free oxygen. These substances reacted with and removed oxygen, so the Earth had a great capacity to prevent the appearance of free oxygen.

The first living bacteria, the procaryotes, consumed chemical nutrients as food, but some adapted the energy of the sun to make their own food. The first photosynthesizing procaryotes, called cyanobacteria or blue-green algae, used light energy to break apart the abundant carbon dioxide and water molecules into carbon food compounds, releasing free oxygen. Fossils dating back 3.6 billion years, show filaments of these single cells stacked end on end. The shape unmistakably resembles spirulina.



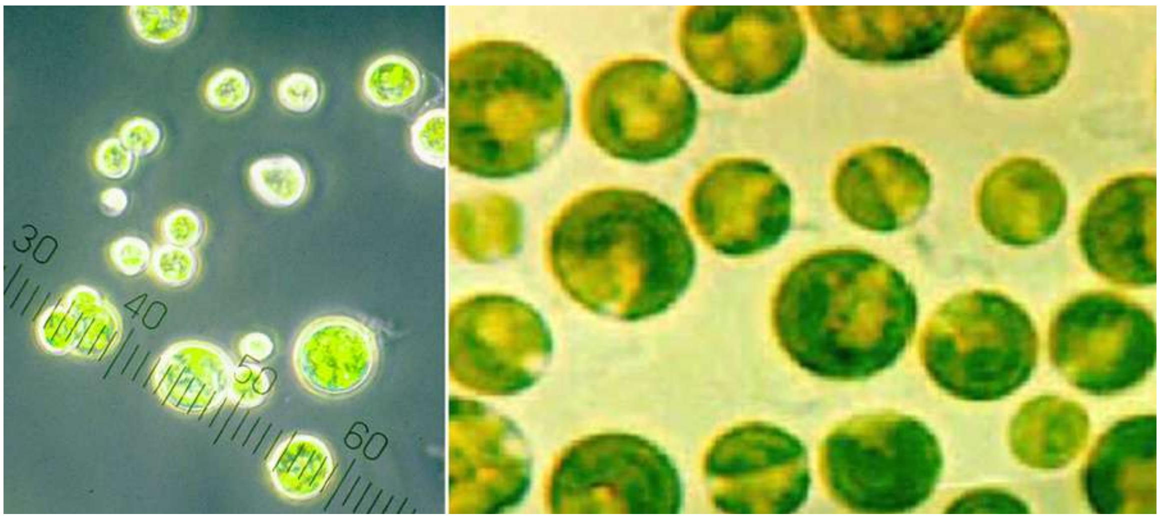
Drawing of a 3.6 billion year old cyanobacteria fossil.



Views of Spirulina in the microscope: 1. Long Filaments. 2. Perfect spiral coils. 3. Electron microscope.

Cyanobacteria colonized the oceans and formed a thin film on land masses. These blue-green algae carried their genetic information in DNA strands in the cell membrane distributing information by exchanging plasmids with another. In this way, the organism became essentially immortal, and one could say linked by its own communication network. Cyanobacteria continued to release ogygen and over a billion years passed.

About 2.3 billion years ago, a new period began when oxygen may have reached a 1% level. Cells with nuclei appeared, a more powerful and complicated life form supported by higher oxygen concentration. These eukaryotes, such as microscopic green algae, may have formed from communities of individual bacteria living within an outer membrane of one of them. The nucleus contained organelles such as chloroplasts, the green bodies that photosynthesize. Because each organelle carried different genetic codes, the loss of information of one of them could mean the death of the cell. To overcome this possibility of death, sex evolved as a way to transfer information between cells.



Chlorella, green microalgae, in the microscope, showing round cell with nucleus.

About 600 million years ago, Earth entered the present phase with the evolution of large plants and animals. The power requirements of larger organisms like trees and dinosaurs needed a higher oxygen concentration, which increased and remained steady at 21%. For hundreds of millions of years, the Earth's biosystem has kept the oxygen level carefully balanced between 15%, where higher life forms cannot survive, and 25%, where forests would spontaneously combust in a global fire.

The procaryotes, cyanobacteria or blue-green algae, still cover the land and water surfaces, part of the living mechanism that help regulate the planet's biosphere. Realizing that algae took billions of years to build and maintain the atmosphere, it is remarkable that humanity has raised the carbon dioxide concentration over 25% in merely one hundred years.

How important is the contribution this original life form? Brian Swimme, in *The Universe is a Green Dragon* wrote: "I think we should take the procaryote as the mascot of the emerging era of the Earth. What better organism to symbolize the vast mystery of the Earth's embryogenesis ... Let's just hope we can emulate some of the achievements of the procaryotes ... To begin with, it would be wonderful if we could contribute something as essential to Earth's life as oxygen."

Thousands of algae species cover the earth

There may be more than 25,000 species of algae, living everywhere. They range in size from a single cell to giant kelp over 150 feet long. Most algae live off sunlight through photosynthesis, but some live off organic matter like bacteria.

Larger algae, like seaweeds, are macroalgae. They already have an important economic role. About 70 species are used for food, food additives, animal feed, fertilizers and biochemicals.

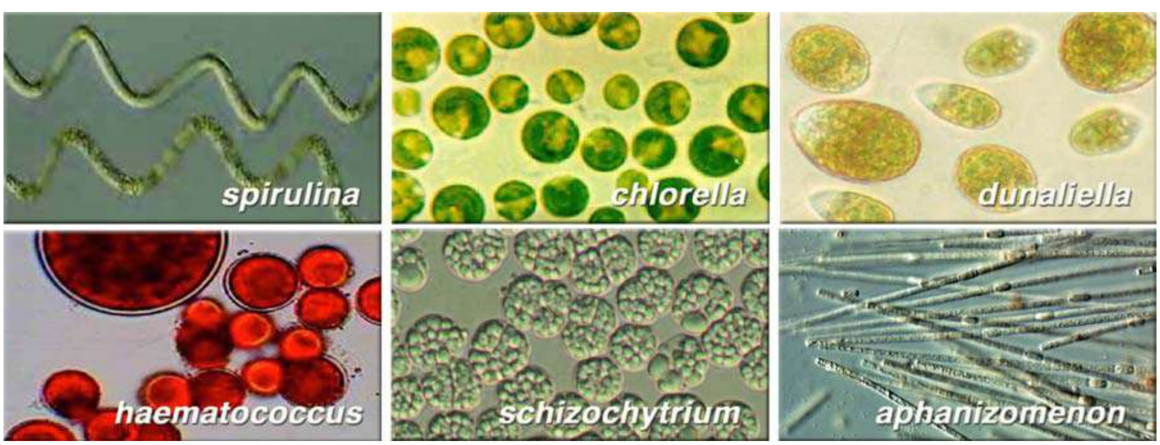
Microalgae can only be seen under a microscope. Some serve a vital role for breaking down sewage, improving soil structure and fertility and generating methane and fuels for energy. Others are grown for animal and aquaculture feeds, human foods, biochemicals and pharmaceuticals.

Ocean microalgae are phytoplankton, and are the base of the food chain supporting all higher life. The rich upwelling of nutrients caused by major currents meeting the continental shelf and nutrients from river basins sustain phytoplankton growth.

Microalgae are everywhere – in water, in soils, on rocks, on plants. Blue-green algae are the most primitive, and contain no nucleus or chloroplast. Their cell walls evolved before cellulose, and are composed of soft *mucopolysaccharides*. Blue-green algae do not sexually reproduce; they simply divide.

Comparing commercially developed microalgae

Microalgae sold as food and feed supplements are *chlorella* (green algae), *spirulina* (blue-green algae), *aphanizomenon flos-aquae* (blue-green algae), *dunaliella* (red algae), *haematococcus* (green algae) and *schizochytrium* (marine microalgae).



Six commercially developed microalgae for food and feed supplements.

Chlorella has been cultivated since the 1970s. Thousands of tons have been sold each year for the past 40 years as a food supplement. Commercial farms in Taiwan, Southern Japan and Indonesia produce much of the world supply.

Dunaliella likes water even saltier than the ocean. This microalgae is too salty to be eaten as a whole food, but its beta carotene is extracted as an oil or powder and sold as a natural food supplement and antioxidant and a color for aquaculture feeds.

Haematococcus is grown in both outdoor ponds and closed systems for *Astaxanthin*, a carotenoid pigment, extracted as a fish feed supplement to color salmon flesh and as an anti-oxidant human food supplement.

Schizochytrium is a marine microalgae grown in vats by fermentation, and developed as a source for docosahexaenoic acid (DHA, C22:6 (omega-3) and used as a supplement in a wide variety of food and feed products.

Aphanizomenon flos-aquae is a nitrogen fixing blue-green algae. Harvested from a lake in Oregon, it is sold a food supplement.

Blue-green algae are cyanobacteria

Many people have asked about differences between two kinds of blue-green algae *spirulina* and *aphanizomenon flos-aquae*.

Blue-green algae is also called cyanobacteria. Some can fix atmospheric nitrogen into organic forms. Organic nitrogen is essential for building proteins and amino acid complexes in plants and animals. Although nitrogen gas comprises 78% of the atmosphere, it is not usable by most plants and animals. For more productive crops, nitrogen must be added to soils. Organic nitrogen can only come from adding chemical fertilizers, from existing microbial mineralization of organic matter, by nitrogen-fixing bacteria in legume roots, or by nitrogen-fixing blue-green algae.

Because of this ability to fix nitrogen, blue-green algae is often the first lifeform to colonize a desolate land area – in deserts, in volcanic rocks, on coral reefs, and even in polar regions, working with lichen to fix nitrogen to the rocks to begin life in the tundra. Nitrogen-fixing blue-green algae are being developed as natural biofertilizers, but they are not always safe to eat. Many kinds of *microcystis*, *anabaena* and *aphanizomenon* are toxic just like some mushrooms and land plants.

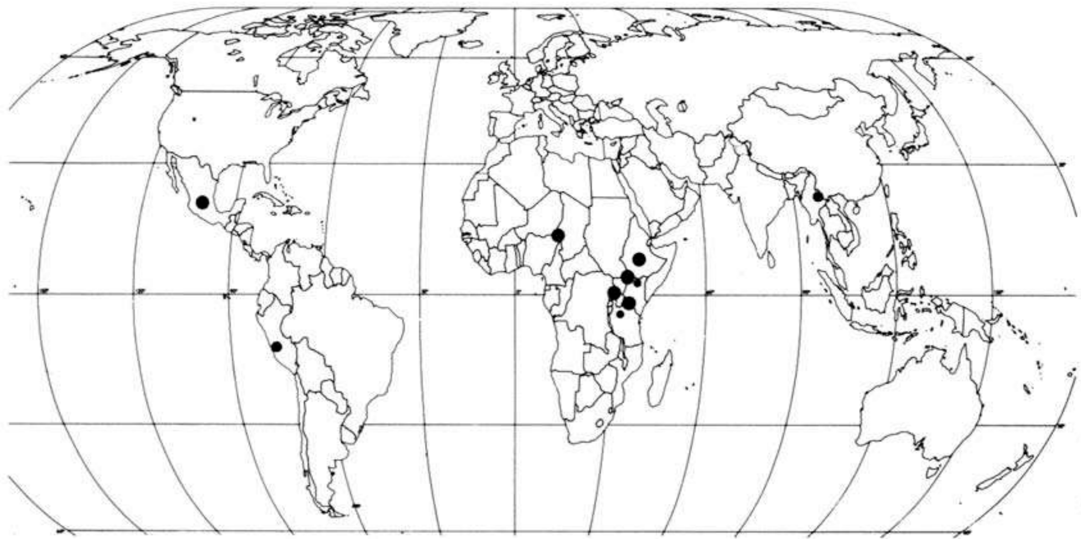
Spirulina is not a nitrogen fixing blue-green algae. It grows in extreme alkaline and high PH environments. Spirulina has a long history of safe human consumption, known to be safe and nutritious. Most kinds of blue-green algae has not been subject to spirulina's long safety testing. Hundreds of published scientific studies over the past thirty years have documented no toxicity.

Spirulina lakes and pink flamingos

In natural lakes, the limited supply of nutrients usually regulates growth cycles. New nutrients come from an upwelling from inside the earth, when rains wash soils into the lakes, or from pollution. The algae grows rapidly, reaches a maximum density, and then dies off when nutrients are exhausted. A new seasonal cycle begins when decomposed algae release their nutrients or when more nutrients flow into the lake.

Spirulina blooms naturally in alkaline or soda lakes around the world. Historical records document traditional peoples harvesting and consuming spirulina from lakes in Mexico Mexico, Africa and Asia.

Some of the largest natural spirulina lakes are in Central Africa around Lake Chad, and in East Africa along the Great Rift Valley. Under normal water conditions, spirulina may be one of many algal species. But the more alkaline water becomes, the more inhospitable to other lifeforms, allowing spirulina to flourish as a single species.



World map showing lakes with natural spirulina blooms.

Lakes Bodou and Rombou in Chad have a stable monocultures dating back centuries. It is predominant in Kenya's lakes Nakuru and Elementeita and Ethiopia's lakes Aranguadi and Kilotes. The lesser flamingo evolved a filter in its beak to eat spirulina.

Huge flocks of pink flamingos populate East African lakes, feeding on spirulina.

Spirulina thrives in alkaline lakes where it is difficult or impossible for other microorganisms to survive. Because the bacteria level in alkaline water is quite low, the bacteria count in spirulina, harvested and dried without further processing, is low. Algae pioneers have dreamed for decades of harvesting from these lakes to feed millions of nearby hungry people and to support a healthy local economy.

Our rediscovery and interest in algae, the original life form, represents a return to the origins of life to understand and heal our planet.

2. First Human Consumption and Cultivation

Algae in historical legends

Microalgae have kept a low profile, but interaction with humans is notable on several occasions. The Bible describes when the Israelites were starving in the wilderness, God provided ‘manna’ – a flake-like thing, lying on the ground. They gathered the manna and baked it into bread. Some believe the manna was a kind of lichen – a combination of fungus and blue-green algae that formed a crust on the rocks and ground.

Another story took place a thousand years ago in Vietnam. A monk named Khong Minh Khong discovered rice was far more productive when a water fern, azolla, was planted in the paddies. The grateful farmers built temples to him after he died, but kept it secret.

Some 700 years later, a woman named Ba Heng rediscovered azolla. Growing rice with azolla continued for centuries, increasing yields and saving many people from starvation. Only this century did scientists discover blue-green algae living on the fern were fixing nitrogen as a natural biofertilizer for the rice.

Although freshwater or inland algae has not been eaten nearly as much as larger marine seaweeds, a survey of historical literature revealed at least 25 separate cases where 9 types of wild freshwater algae were collected and eaten in 15 countries. This non-seaweed algae has been used in a variety of soups, spreads and sauces and may have been an important source of vitamins and minerals.

When microscopic algae could be easily collected because it formed into larger colonies of mats or globules, it played a culinary and therapeutic role similar to many higher plants. So, eating algae may have been limited only by the difficulty of collecting these tiny organisms. Two cases, on separate continents, involved spirulina.

Rediscovery of the human use of spirulina

Dihé in Chad

In 1940, a little known journal published a report by French phycologist Dangeard on a material called dihé, eaten by the Kanembu people near Lake Chad. Dihé is hardened cakes of sun-dried blue-green algae collected from the shores of small ponds around Lake Chad. Dangeard also heard this same algae populated a number of lakes in the Rift Valley of East Africa, and was the main food for flamingos living around those lakes. The report went unnoticed.

Kanenbu Spirulina Ladies harvesting spirulina from Lake Boudou Andja.
Photos by Marzio Marzot from the FAO Report The Future is an Ancient Lake, 2004.

Two decades later, in 1964, the botanist with a Trans-Saharan expedition, Jean Léonard, noticed blue-green algae growing in the wadis (pools) that form to the northeast of Lake Chad after the rainy season. He then came across curious blue-green cakes in native markets of Fort Lamy (now Ndjemena) in Chad. When locals said these cakes came from areas near Lake Chad, Leonard recognized the connection between the algal blooms and dried cakes sold in the market. He observed that 70 percent of the food of the Kanembu was accompanied by a sauce made with these dried cakes.

Ladies harvesting and traditionally drying spirulina dihé in a sand filter.
Photos by Marzio Marzot from the FAO Report The Future is an Ancient Lake, 2004.

Techniques of harvesting and drying have been passed from mother to daughter for generations. When the rains stop, Kanembu ladies scoop the wet algae in clay pots, drain the water through bags of cloth and spread out the algae a circular sand filter to dry in the sun. After about 20 minutes of drying, women cut the algae cakes into small squares for sale in the local market. Dihé is crumbled and mixed with a sauce of tomatoes and peppers, and poured over millet, beans, fish or meat.

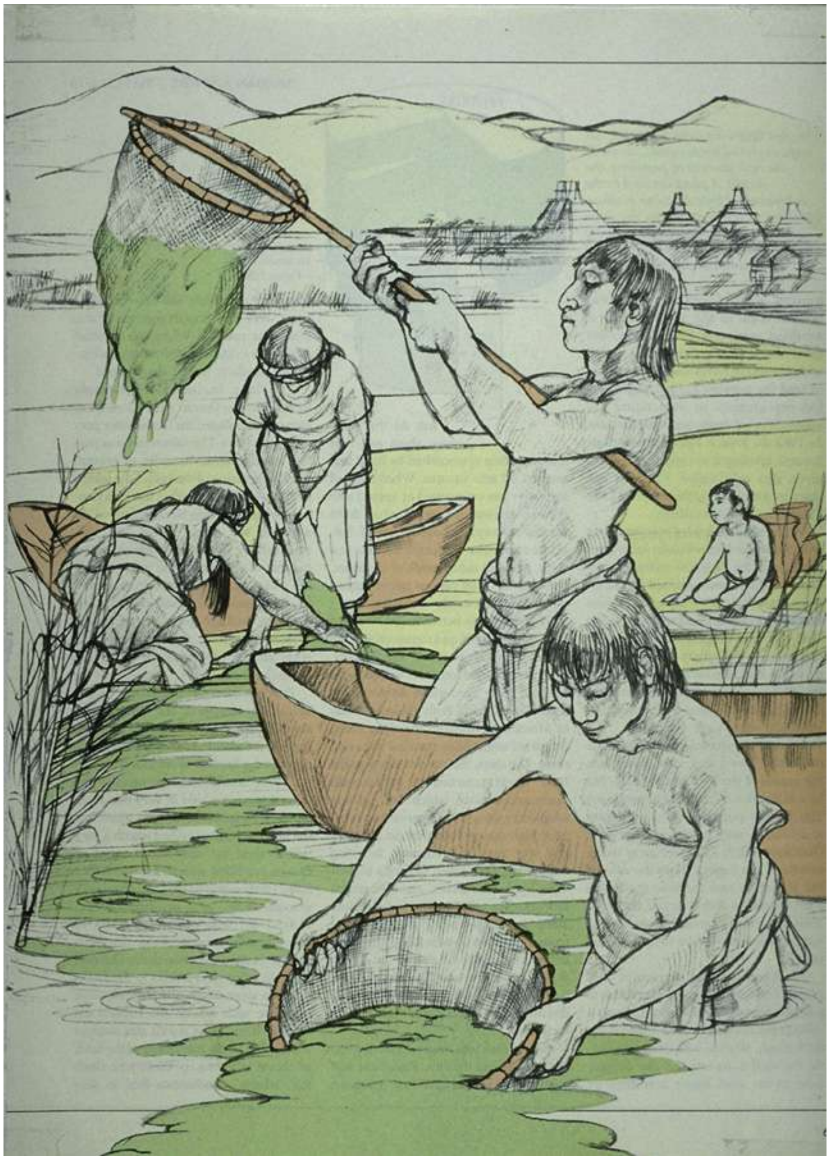
Selling dihé in the local market. Locals use dihé sauce poured over millet.
Photos by Marzio Marzot from the FAO Report The Future is an Ancient Lake, 2004.

In 2004 the United Nations Food and Agriculture Organization (FAO) reported in the Kanem region of Chad, the local market price ranged from $.80 to $2 per kg – more than 10 times less than spirulina sold in developed countries. The average consumption of dihé could be as high as 50 grams per person per week. More than 250 dry tons per year is produced, making these ladies of Chad nearly the highest volume and certainly the lowest cost producer of spirulina in the world.

Techuitlatl in Aztec Mexico

Around the same time in the 1960s, a company director in Mexico, Hubert Durand-Chastel, read about spirulina and realized it was the same algae clogging the soda extraction plant on Lake Texcoco. Although spirulina was not then eaten as a food in Mexico, an historical literature search revealed it had been harvested, dried and sold for human consumption 400 years earlier at the time of the Spanish conquest.

Spanish chroniclers described fisherman with fine nets collecting this blue colored 'techuitlatl' from the lagoons and making bread or cheese from it. Other legends say Aztec messenger runners took spirulina on their marathons. Techuitlatl was mentioned until the end of the 16th century, but not after that. Probably it disappeared soon after the Spanish conquest. The great lakes in the Valley of Mexico were drained to make way for the new civilization. The only remnant today, Lake Texcoco, still has a living algae culture.



***Aztecs harvesting blue-green algae from lakes in the valley of Mexico.
Drawing in Human Nature, March 1978. (by Peter T. Furst).***

Algae cultivation is an evolutionary step in agriculture

Over thousands of years, humans have increased food productivity at progressively greater environmental costs. Domesticating plants and animals encouraged the first permanent human settlements. About 7000 years ago, irrigation brought water to the land and food surpluses supported the first great river valley civilizations. Thousands of years later, when the land salted up from over-irrigation, these civilizations vanished.

A thousand years ago, the invention of an efficient plough in Europe allowed easier tilling of the soil. Europeans cut down the vast original forests bringing new areas under cultivation and new prosperity. The 19th century industrial revolution introduced mechanized agriculture, climaxing with the so-called 'Green Revolution' exported from the United States in the 1960s and 1970s.

Modern agriculture raised short-term productivity by using seed hybrids and massive fertilizer, pesticide, water and energy inputs. Productivity has been achieved by ignoring hidden costs, such as consumption of non-renewable fossil fuels for fertilizers and machinery, pollution of soil and water through excessive use of chemical fertilizers, and depletion of soils. This ecological damage will be borne by future generations.

Successful algae cultivation requires a more ecological approach. A spirulina pond is a living culture and the whole system must be considered. If one factor changes, the entire pond environment changes – quickly. Because algae grows so fast, the result can be seen in hours or days, not seasons or years like in conventional agriculture.

Algae scientists talk of 'balancing pond ecology' for sustainable growth. Pesticides and herbicides would kill many microscopic life forms in a pond, so algae scientists have learned how to balance pond ecology to keep out weed algae and zooplankton algae eaters without using pesticides or herbicides. Algae cultivation is a new addition to ecological food production.

Scientists discovered spirulina had been safely consumed for hundreds of years by traditional peoples and showed nutritional and therapeutic health benefits. Spirulina had three great advantages over other microalgae: 1. Documented history of safe human consumption. 2. Grows well in warm, highly alkaline and high pH water, and in those conditions can grow as a pure culture. 3. With a long spiral shape filament, it is relatively easy to harvest.

A spirulina farm can be an environmentally sound green food machine. Cultivated in shallow ponds, biomass can double every 2 to 5 days. This productivity breakthrough yields over 20 times more protein than soybeans on the same area, 40 times corn and 400 times beef. Spirulina can flourish in ponds of brackish or alkaline water on already unfertile land. In this way, it can augment the food supply not by clearing the disappearing rainforests, but by cultivating the expanding deserts.

However, it hadn't been done yet! No one had successfully cultivated spirulina on a large scale and convinced anyone they should indeed eat algae! If it was indeed an idea whose time had come, it was, nonetheless, a daunting task.

The first spirulina bioneers emerge around the world

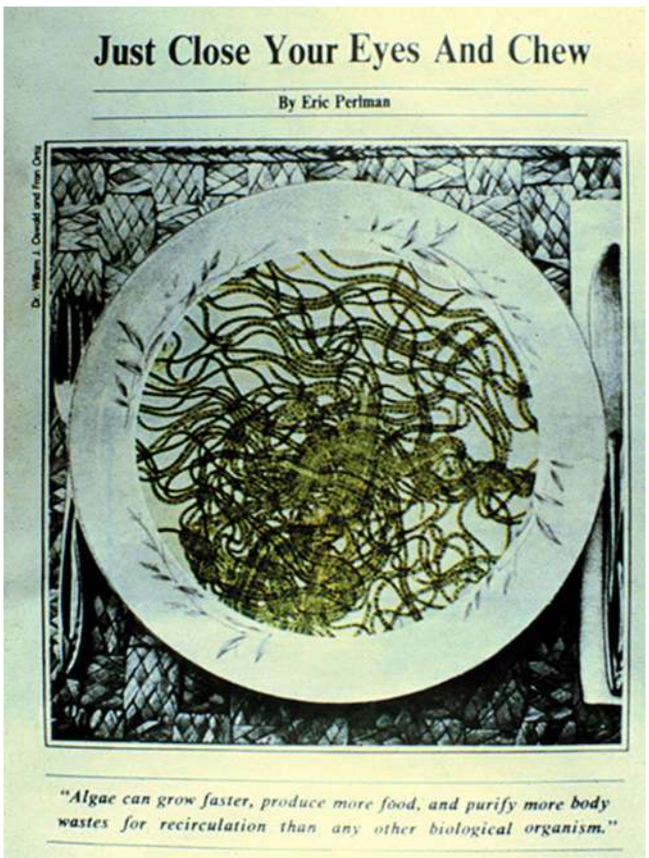
In one of the first books on algae, "Spirulina, the Whole Food Revolution", Larry Switzer wrote: "For the first time since the appearance of man, both wilderness and food productivity can be increased simultaneously with a new technology. This is a choice that man has never had before. The rediscovery of this ancient life as a human food has great implications for us all, now and in the 21st century. It is an example of the myriad of unexpected and astounding solutions to basic world problems that are now beginning to appear together on this planet."

A new planetary idea often incarnates through many messengers. This was true with spirulina. Hubert Durand-Chastel encouraged the soda ash company to set up a farm in Lake Texcoco in the 1970s, and it became the world's largest spirulina farm by the 1980s. He became Senator of France and spirulina promoter.

Larry Switzer founded Proteus in 1976, and was joined by Robert Henrikson, Alan Jassby and Ronald Henson. This team began spirulina cultivation in California's Imperial Valley in 1977. This demonstration farm led to the founding of Earthrise Farms in 1981, which became the world's largest spirulina farm by the 1990s.

Dainippon Ink & Chemicals (DIC) of Japan, established Siam Algae Company in Thailand in 1980. Former DIC Presidents, Shigekuni Kawamura and Takemitsu Takahashi, were long time spirulina sponsors. Heading the program was "Mr. Spirulina" in Japan, Hidenori Shimamatsu. DIC and Proteus formed Earthrise Farms in 1981.

In the early 1980s, Cyanotech began spirulina production in Hawaii and growers in Taiwan emerged. Israeli, Indian and European scientists conducted cultivation research. Others focused on village scale and appropriate technology farms, notably Dr. Ripley D. Fox and Dr. C.V. Sesahdri of India.



Spirulina began selling in Japan and Mexico as a health food and specialty fish feed in the late 1970s. In the USA it was introduced in 1979 through natural food stores and network marketing. By the early 1980s, marketing algae as a specialty food supplement was picking up momentum.

The San Francisco Examiner article in 1977 "Just Close Your Eyes and Chew" introduced spirulina as "Food of the Future".

3. An Impressive Nutritional Profile

Spirulina called a superfood because its nutrient profile and unusual phytonutrients are more potent than any other food, plant, grain or herb.

Its 65% protein content is higher than any other natural food. Yet, an even greater value is found in its concentration of vitamins and minerals. Three to ten grams a day delivers impressive amounts of beta carotene, vitamin B-12 and B complex, iron, essential trace minerals and gamma-linolenic acid. Beyond vitamins and minerals, spirulina is rich in pigments, polysaccharies and other nutrients that benefit health.

For undernourished people in the developing world, spirulina brings quick recovery from malnutrition. In Western overfed food culture loaded with unhealthy and depleted foods, spirulina can renourish our bodies and renew our health.

It is legally approved as a food or food supplement in Europe, Japan and many other countries around the globe. The United States Food and Drug Administration confirmed in 1981 that spirulina is a source of protein and contains various vitamins and minerals and may be legally marketed as a food supplement. Spirulina has GRAS status (Generally Accepted as Safe).

Today's food is lower in essential nutrients than foods produced 50 years ago. Farming practices have depleted our soils of minerals. Microorganisms in the soil contributing the valuable mineral content are declining because the overuse of chemical fertilizers destroys these microorganisms. At the same time, stress from environmental pollutants and lifestyle demands have increased dietary requirements for certain essential nutrients. Today, at least some supplements are used by almost everyone.

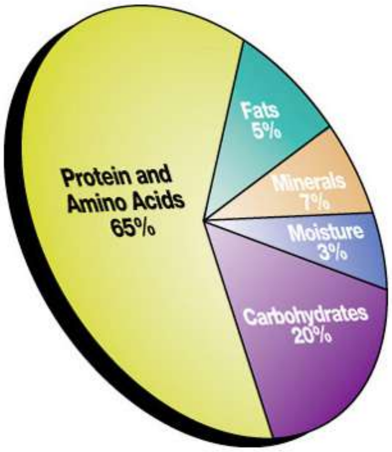
Most people believe it is better to get nutrients from natural foods. Since many conventional foods are nutrient depleted, more people are taking spirulina and green superfoods. These whole foods offer functional nutrients, new frontiers for disease prevention research, way beyond isolated vitamin and mineral supplements.

Digestible protein and amino acids, low fat and calories

Spirulina has the highest protein of any natural food (65%); more than animal and fish flesh (15-25%), soybeans (35%), dried milk (35%), peanuts (25%), eggs (12%), grains (8-14%) or whole milk (3%).

Spirulina cell walls are composed of soft mucopolysaccharides, making it easily digested and assimilated, especially important for people suffering from intestinal malabsorption. Typically, many older people have difficulty digesting complex proteins, and are on restricted diets. They find spirulina's protein easy to digest. Spirulina is effective for victims of malnutrition diseases like kwashiorkor, where intestinal absorption has been damaged.

Spirulina's fat content is only 5%, far lower than almost all other protein sources. Ten grams has only 36 calories and virtually no cholesterol. This means spirulina is a low-fat, low-calorie, cholesterol-free source of protein.



Spirulina vitamin content

Vitamins	per 10 grams	U.S. DV	% DV
Vitamin A (beta carotene)	23000 IU	5000 IU	460 %
Vitamin C	0 mg	60 mg	0 %
Vitamin E (a-tocopherol)	1.0 IU	30 IU	3 %
Vitamin K	200 mcg	80 mcg	250 %
Vitamin BI (thiamin)	0.35 mg	1.5 mg	23 %
Vitamin B2 (riboflavin)	0.40 mg	1.7 mg	23 %
Vitamin B3 (niacin)	1.40 mg	20 mg	7 %
Vitamin B6 (pyridoxine)	80 mcg	2 mg	4 %
Folate (folic acid)	1 mcg	0.4 mg	0 %
Vitamin B12 (cyanocobalamin)	20 mcg	6 mcg	330 %
Biotin	0.5 mcg	0.3 mg	0 %
Panthothenic Acid	10 mcg	10 mg	1 %
Inositol	6.4 mg	***	***

Potent vitamins, protectors of health

Beta Carotene*.* Spirulina is the richest beta-carotene food, ten times more concentrated than carrots. Ten grams provide 460% of the U.S. Daily Value (DV) of Vitamin A. Human bodies convert beta carotene to Vitamin A only as needed. Vitamin A deficiency is one of the most serious malnutrition diseases in the developing world, leading to blindness.

Beta carotene has therapeutic effects, including reducing serum. Cancer health authorities have published studies showing beta carotene may reduce risks of all kinds of cancers. Since increase in cancer rates seems to be caused by environmental factors, especially diet, these risks can be reduced by increasing protective factors, especially beta carotene, in the diet.

Spirulina contains an antioxidant complex of ten carotenoids. These mixed carotenes and xanthophylls function at different sites in the body and work synergistically with the other essential vitamins, Vitamin E, minerals and phytonutrients in spirulina. Even if you don’t eat the recommended 4 to 9 servings of fruits and vegetables every day, get natural carotenoid antioxidant protection from spirulina every day.

Vitamin B-12 and B-complex vitamins. Spirulina is the richest source of B-12, higher than beef liver, chlorella or sea vegetables. B-12 is necessary for development of red blood cells, especially in the bone marrow and nervous system. Although primary B-12 deficiencies, pernicious anemia and nerve degeneration, are quite rare, because B-12 is the most difficult vitamin to get from plant sources, vegetarians have taken to spirulina.

Ten grams contain 20 mcg of Vitamin B-12, 330% DV, using microbiological assay. There has been scientific controversy over the methodology used to measure Vitamin B-12 and its analogs. Yet, in 30 years, there have been no complaints of a vitamin B-12 deficiency from spirulina consumers, including children and vegetarians.

One tablespoon provides significant quantities of thiamin (23% DV), riboflavin (23% DV) and niacin (7% DV). Spirulina is a richer source of these vitamins than common whole grains, fruits and vegetables and some seeds. Other B vitamins, B-6, niacin, biotin, panthothenic acid, folic acid, inositol and Vitamin E are also present in smaller amounts.

Best beta carotene vegetables[a]

Food	serving size	IU of beta carotene
spirulina[b]	**1 heaping tbsp. (10 g)**	**23000**
papaya	1/2 medium	8867
sweet potato	1/2 cup, cooked	8500
collard greens	1/2 cup, cooked	7917
carrots	1/2 cup, cooked	7250
chard	1/2 cup, cooked	6042
beet greens	1/2 cup, cooked	6042
spinach	1/2 cup, cooked	6000
cantaloupe	1/4 medium	5667
chlorella[c]	**50 tablets (10 g)**	**5000**
broccoli	1/2 cup, cooked	3229
butternut squash	1/2 cup, cooked	1333
watermelon	1 cup	1173
peach	1 large	1042
apricot	1 medium	892

a. Vegetarian Times, "Recipes with A+ Nutrition", May 1986, pg 47.
b. Earthrise Farms, 1995. c. Yaeyama Chlorella, 1995.

Best food sources of Iron[a]

Food	serving size	mg Iron
Spirulina[b]	**1 tbsp. (10g)**	**10.0**
Chlorella[c]	**1 tbsp. (10g)**	**10.0**
Chicken liver, cooked	3 ounces	7.2
Crab, pieces, steamed	1/2 cup	6.0
Beef liver, fried	1/2 cup	5.3
Soybeans, boiled	1/2 cup	4.4
Blackstrap molasses	1 tbsp.	3.2
Spinach, cooked	1/2 cup	3.2
Beef, sirloin, broiled	3 ounces	2.9
Potato, baked	one	2.8
Scallops, steamed	3 ounces	2.5
Pistachios, dried	1/4 cup	2.2
Broccoli, cooked	1 spear	2.1
Cashews, dry-roasted	1/4 cup	2.1
Turkey, dark meat	3 ounces	2.0
Spinach, raw chopped	1/2 cup	0.8

a. The Complete Book of Vitamins and Minerals for Health, pg. 182.
b. Earthrise Farms, 1995. c. Yaeyama Chlorella, 1995.

Naturally colloidal minerals

Algae absorb trace minerals while growing and these are well assimilated by the human body. Its mineral content depends on where it is grown and the minerals in the water.

The best natural iron supplement. Iron is the most common mineral deficiency worldwide, especially for women, children and older people. Women on weight loss diets typically do not get enough iron, and can become anemic. Iron is essential for strong red blood cells and a healthy immune system. Spirulina is a rich iron food, 10 times higher than common iron foods. Ten grams can supply up to 10 mg of iron, 55% RDV.

Spirulina iron is easily absorbed. It is theorized that its blue pigment, phycocyanin, forms soluble complexes with iron and other minerals during digestion making iron more bioavailable. Hence, iron in spirulina is over twice as absorbable as the form of iron in vegetables and most meats and 60% better absorbed than iron supplements such as iron sulfate.

Calcium, magnesium, zinc and trace minerals. Spirulina is a concentrated calcium food, supplying more, gram for gram, than milk. Ten grams supply 7% DV for calcium. Calcium is important for bones and neural transmissions to the muscles and deficiencies can lead to osteoporosis in older women. Ten grams supply 10% DV for magnesium, one of the most concentrated magnesium foods. Magnesium facilitates absorption of calcium and helps regulate blood pressure. Spirulina is low in sodium, and is no problem for those on salt-restricted diets.

Humans need dozens of essential trace minerals for the functioning of enzyme systems and many other physiological functions. Deficiency of trace minerals in the typical diet are thought to be widespread. Ten grams supply manganese (25% DV), chromium (21% DV), selenium (14% DV), copper (6% DV) and zinc (2% DV).

Essential fatty acids

Humans require dietary essential fatty acids (EFA). Spirulina has 4 to 7% lipids, and most of these are essential fatty acids. Ten grams have 225 mg of EFA as linoleic and gamma-linolenic acid (GLA). Ten grams provide 8 to 14% DV, depending on sex and age group.

GLA is the precursor to the body's prostaglandins – master hormones that control many functions. Dietary saturated fats and alcohol can cause in GLA deficiency and suppressed prostaglandin formation. Studies show GLA deficiency figures in many diseases and health problems, so a food source of GLA can be important. The other known sources of dietary GLA are mother's milk and oil extracts of evening primrose, black currant and borage seeds.

Spirulina essential fatty acids

		mg per 10 grams	% total
C 14:0	Myristic	1 mg	0.2 %
C 16:0	Palmitic	244 mg	45.0 %
C 16:1	Palmitoleic	33 mg	5.6 %
C 17:0	Heptadecanoic	2 mg	0.3 %
C 18:0	Stearic	8 mg	1.4 %
C 18:1	Oleic	12 mg	2.2 %
C 18:2	Linoleic	97 mg	17.9 %
C 18:3	**Gamma-linolenic**	**135 mg**	**24.9 %**
C 20	Others	14 mg	2.5 %
Total		**546 mg**	**100 %**

Dietary sources of GLA

Food sources	Oil extracts
Mother's milk	Evening primrose plant
Spirulina	Black currant and borage seeds

Spirulina natural pigments

Pigments[a]	Color	per 10 grams	% total
Phycocyanin	**(blue)**	**1400 mg**	**14 %**
Chlorophyll	**(green)**	**100 mg**	**1.0 %**
Carotenoids	**(orange)**	**37 mg**	**0.37 %**
Carotenes	***54 %***	***20 mg***	***0.20 %***
Beta carotene	45 %	17 mg	0.17 %
Other Carotenes	9 %	3 mg	0.03 %
Xanthophylls	***46 %***	***17 mg***	***0.17 %***
Myxoxanthophyll	19 %	7 mg	0.07 %
Zeaxanthin	16 %	6 mg	0.06 %
Cryptoxanthin	3 %	1 mg	0.01 %
Echinenone	2 %	1 mg	0.01 %
Other Xanthophylls	6 %	2 mg	0.02 %

A rainbow of pigments and phytonutrients

These functional nutrients have no Recommended Daily Value, but are known to benefit health. They include pigments and polysaccharides. Pigments help synthesize enzymes necessary for regulating the body's metabolism. Spirulina's dark color comes from natural pigments that harvest different wave lengths of sunlight.

Phycocyanin (algae-blue). This protein complex is about 14% of spirulina. Phycocyanin evolved a billion years before chlorophyll and may be the precursor to chlorophyll and hemoglobin. Much research suggests it stimulates the immune system.

Chlorophyll (nature's green magic). Chlorophyll is known for cleansing and detoxifying. Sometimes called 'green blood' because it looks like the hemoglobin molecule in human blood. Spirulina's beneficial effect on anemia could be due to this similarity of chlorophyll and hemoglobin and its high bioavailable iron. Spirulina has 1% chlorophyll, one of nature's highest levels, and Chlorella has 2 to 3%.

Carotenoids (natural antioxidants). About half of the yellow/orange pigments in spirulina are carotenes: Alpha, Beta and Gamma. About half are xanthophylls. Although beta carotene is best known, this mixed carotenoid complex functions at different sites in the body and works synergistically to enhance antioxidant protection.

Polysaccharides. Spirulina contains 15 to 25% carbohydrate and sugar. The primary forms of carbohydrates are rhamnose and glycogen, two polysaccharides easily absorbed by the body with minimum insulin intervention. Spirulina offers quick energy, without taxing the pancreas or precipitating hypoglycemia.

Glycolipids and Sulfolipids. When NCI announced that sulfolipids in blue-green algae were 'remarkably active' against the AIDS virus, attention was focused on the sulfolipid containing glycolipids. 40% of the lipids are glycolipids and sulfolipids range from 2-5%.

Health benefits beyond the nutritional profile

For over 30 years, people have reported heath benefits from small daily supplements of algae, like spirulina. The nutritional profile of algae protein, vitamins and minerals, however impressive, does not fully account for these therapeutic results. But a remarkable body of published scientific evidence has been accumulating from around the world, explaining how as little as 3 to 5 grams of spirulina per day, one teaspoon or 10 tablets, can be effective in supplying some extraordinary health benefits.

4. Scientific Research Reveals Health Benefits

An international detective hunt has been underway for 40 years. Researchers in Japan, China, India, Europe, USA and other countries are discovering how and why this algae is effective for human and animal health. Hundreds of published and reviewed scientific studies have focused on spirulina - how this food, its phytonutrients and extracts boost the immune system and improve health.

A more complete scientific bibliography and reference guide is available in the book Spirulina Whole Food and at SpirulinaSource.com. The following summary briefly touches on some important areas of research and findings that spirulina:

- Stimulates the immune system.
- Increases anti-viral activity.
- Offers anti-aging and neuroprotective benefits.
- Reduces risk of cancer.
- Reduces kidney toxicity.
- Builds healthy lactobacillus.
- Overcomes malabsorption and malnutrition.
- Improves wound healing.
- Reduces radiation sickness.

Supports immune system for people over 50: New research continues to be announced. A UC Davis study will be published in the March 2011 Journal of Cellular & Molecular Immunology, *"The effects of Spirulina on anemia and immune function in senior citizens."* The report suggests taking spirulina as a supplement may improve immune function and ameliorate anemia in persons over 50.

Anti-viral activity. There are peer reviewed scientific studies about spirulina's ability to inhibit viral replication, strengthen the immune system and cause regression and inhibition of cancers.

U.S. scientists announced preliminary research, documenting that a water extract of spirulina inhibits HIV-1 replication in human derived T-cells and in human blood mononuclear cells. Small amounts of the extract reduced viral replication, while higher concentration totally stopped its reproduction. The extract seemed to prevent the virus from penetrating the cell membrane, therefore the virus was unable to replicate.

In 1989, the NCI announced that chemicals from blue-green algae were found to be "remarkably active" against the AIDS virus. These are the naturally occurring sulfolipid portions of the glycolipids. Sulfolipids can prevent viruses from either attaching to or penetrating into cells, thus preventing viral infection.

Anti-cancer effects. Studies show beta carotene rich spirulina or its extracts prevent or inhibit cancers in humans and animals. Some common forms of cancer are thought to result from damaged cell DNA causing uncontrolled cell growth. In a US study, spirulina extracts reduced oral cancer cells. A beta carotene solution applied to cancerous tumors in mouths of hamsters reduced the number and size of tumors or caused them to disappear. In India, spirulina reversed oral cancer in pan tobacco chewers in Kerala. An Israeli study showed natural beta carotene is more effective than synthetic.

Clinical Research with Spirulina

Medical Subject	Patient	Country	Year
Anti-Aids viral effect	human cells	USA	1996
Anti-viral effect	human cells	Japan	1996
Anti-herpes viral effect	hamsters	Japan	1993
Lowering cholesterol	humans	Japan	1988
Lowering cholesterol	rats	India	1983
Lowering cholesterol	rats	Japan	1984, 90
Anti-aging neuroprotective	rats	USA	2002
Anti-aging neuroprotective	humans	Japan	2002
Anti-aging neuroprotective	rats	Brazil	1998
Reducing oral cancer tumors	hamsters	USA	1986, 88
Reducing oral cancer tumors	humans	India	1995
Anti-liver cancer tumor	mice	Japan	1982
Builds bone marrow	mice	China	1994
Immune enhancement	rabbits	Russia	1979
Immune enhancement	mice	Japan	1994
Immune enhancement	mice	China	1991, 94
Immune enhancement	chickens	USA	1995, 96
Immune enhancement	cats	USA	1996
Reducing kidney poisons	rats	Japan	1988
from drugs and heavy metals	rats	Japan	1990
Reducing liver toxin from dioxin	rats	Japan	1997
Effect against diabetes	rats	Japan	1991

Clinical Research with Spirulina

Medical Subject	Patient	Country	Year
Reduces blood pressure	rats	Japan	1990
Building healthy lactobacillus	rats	Japan	1987
Treating external wounds	humans	France	1967
Treating external wounds	humans	Japan	1977
Infection (antibiotic action)	microbial cells	PuertoRico	1970
Infection (antibiotic action)	microbial cells	India	1978
Recovering from malnutrition	humans	Mexico	1973
Recovering from malnutrition	humans	Togo	1986
Treating nutritional deficiencies	humans	India	1991, 93
Treating nutritional deficiencies	humans	Romania	1984
Treating nutritional deficiencies	humans	China	1987, 94
High iron bioavailability	rats	USA	1986
Correcting iron anemia	rats	Japan	1982
Correcting iron anemia	humans	Japan	1978
Iron deficit in athletes	humans	Macedonia	1998
Treating infirmities with GLA	humans	Spain	1987
Weight lowering effect	humans	Germany	1986
Radiation protective effects	mice	China	1989
Reducing radionucleides	humans	Belarus	1993
Reducing radiation allergies	humans	Russia	1994
Detoxify radiation pollutants	humans	Belarus	1999

Strengthens the immune system. Spirulina is a powerful tonic for the immune system. In studies of mice, hamsters, chickens, turkeys, cats and fish, it improves immune system function. It not only stimulates the immune system, it enhances the body's ability to generate new blood cells. Spirulina upregulates key cells and organs, improving their ability to function in spite of stresses from environmental toxins and infectious agents.

Anti-aging and neuroprotective effects. Multiple studies suggest spirulina should be considered therapeutic intervention for the aging brain. Many beneficial outcomes of spirulina could be linked to the activation of the innate immune system, first line of defense in our bodies. The inflammation seen with normal aging can be down regulated with spirulina, as seen by the benefits of spirulina administration in arthritis. Spirulina has actions in the central nervous system to counterract oxidative stress and inflammation that occur as a consequence of aging and to aid regeneration of the brain following injury or neurodegenerative disease.

Reduces kidney and liver toxicity from mercury, drugs and chemical pollutants. Kidneys play an essential role in cleansing the body of toxins. Scientists are interested in substances that can help cleanse the kidneys of toxic side effects from heavy metal poisoning or from high intake of medicines or pharmaceutical drugs. In Japan, studies with rats suggest spirulina phycocyanin extract may have a beneficial effect for humans suffering from heavy metal poisoning.

Phycocyanin enhances the immune system. Research in Japan suggests phycocyanin raises lymphocyte activity and acts by strengthening the body's resistance through the lymph system. Phycocyanin may be active in preventing degenerative organ diseases by boosting immunity. A Japanese patent states a small dosage of phycocyanin daily maintains or accelerates normal control cell functions that prevents generation of malignancy such as cancer or inhibits its growth or recurrence.

Polysaccharides enhance the immune system. In 1979, Russian scientists published initial research on the immune stimulating effects on rabbits from lipopolysaccharides in spirulina. More recent studies in China and Japan have shown polysaccharide extracts increased macrophage function, antibody production and infection fighting T-cells.

Phycocyanin builds blood. Studies show phycocyanin in spirulina affects the stem cells found in bone marrow. Stem cells are "grandmother" to both the white blood cells that make up the cellular immune system and red blood cells that oxygenate the body. Chinese scientists document Phycocyanin stimulating hematopoiesis (the creation of blood), regulating production of white blood cells, even when bone marrow stem cells are damaged by toxic chemicals or radiation.

Reduces radiation sickness. Spirulina has been used in Ukraine and Belarus as a "medicine food" for treating radiation sickness. The Children of Chernobyl suffered radiation poisoning from eating food grown on radioactive soil. Their bone marrow was damaged, rendering them immunodeficient. Radiation damaged bone marrow cannot produce normal red or white blood cells. The children were anemic and suffered from terrible allergic reactions. Children fed five grams each day made dramatic recoveries within six weeks. Research continuing through 1999 in Belarus showed immune building, normalization of peroxide lipid oxidation and detoxifying effects of spirulina supplements in children and teenagers.

Doctor and child radiation victim at a medical clinic in Belarus.
Nurse introduces child to spirulina at a village clinic in Togo.

Builds healthy lactobacillus, overcomes malabsorption. Healthy lactobacillus in the intestines provides humans with three major benefits: better digestion and absorption, protection from infection, and stimulation of the immune system. Spirulina acts as a functional food, feeding beneficial intestinal flora, lactobacillus and bifidus. Japanese studies show when spirulina is added to the diet, beneficial intestinal flora increase. One strategy for halting the progression of AIDS is based on supplementation (to correct malabsorption) and lactobacillus (to maintain proper intestinal flora and prevent infection).

Benefits for malnourished children. Numerous studies from around the world showing rapid recovery of malnourished children attribute spirulina's ability to rebuild intestinal flora and improve overall nutrient absorption and its beta carotene to help children recover from Vitamin A deficiency.

Iron bioavailablity and correction of anemia. Iron is the most common mineral deficiency worldwide. Iron anemia is prevalent in women, children, older people, and women on weight loss diets. Iron is essential for healthy red blood cells and a strong immune system, but typical iron supplements are not well absorbed by the human body. Spirulina fed rats absorbed 60% more iron than rats fed an iron supplement, suggesting a highly available form of iron in spirulina.

Wound healing and antibiotic effects. People have used spirulina in face creams and body wraps and in baths to promote skin health. The Kanembu in Chad use freshly harvested algae as a skin poultice for treating certain diseases. Pharmaceutical compounds in France containing spirulina accelerated wound healing. Patients used whole spirulina, raw juice and extracts in creams, ointments, solutions and suspensions. A study in Japan showed cosmetic packs containing spirulina and its enzymatic hydrolyzates promoted skin metabolism and reduced scars. Other research showed extracts of spirulina inhibited the growth of bacteria, yeast and fungi.

Self care strategies with spirulina

Spirulina is most effective when used in a natural food diet as one part of a personal strategy for self-care. This strategy embraces recommendations by the National Academy of Science, the National Cancer Institute and the American Heart Association.

- Eating lighter as part of a natural weight control plan.
- Reducing risks of heart disease and cancer.
- Fasting and body cleansing programs.
- More energy, endurance and faster recovery for athletes and body builders.
- For older people on restricted diets, good nutrient absorption
- Anti-aging strategy for immune enhancement and neuroprotection.
- Great for children and nursing mothers.

Most popular ways are taking convenient tablets or mixing a teaspoon to tablespoon of power in a blender with fruit for a green smoothie. Spirulina recipe books have many more ideas for using algae in foods.

Green superfoods have become popular over the past 30 years. Spirulina and chlorella are specially cultivated algae. Aphanizomenon flos-aquae (called ‘blue-green algae’) is harvested from a lake in Oregon. Barley and wheat grass are cultivated young cereal plants, harvested before they become grains. All five are chlorophyll-rich foods, and often are combined with other vitamins and minerals in green superfood supplements.

Author’s note: Having read these scientific research reports over many years, the author has consumed spirulina tablets or powder daily for more than 30 years. In the morning, before getting started for the day, five grams or 10 spirulina tablets each day.

Green food drink mixes with spirulina and other superfood concentrated nutrients are popular supplements.

5. Development of a Spirulina Industry – Production

Worldwide spirulina algae production systems

Over the past 30 years, the spirulina industry has been supplied by many small to large scale farms around the world, using a wide range of algae production systems.
• Lake harvesting of spirulina growing in natural lakes.
• Commercial farms using outdoor raceway pond systems.
• Enclosed photobioreactors, tubular or tank systems.
• Integrated commercial production farms.
• Village farms in the developing world with appropriate technology.
• Microfarms, family and community size production systems.

Lake harvesting and cultivation systems

Chad: Indigenous Kanembu women have seasonally harvested spirulina dihé from the alkaline ponds near lake Chad. The UN has estimated annual production of at least 250 dry tons per year sold on the local market. In recent years, improved harvesting and drying techniques have been introduced.

Mexico: Spirulina grows naturally in lake Texcoco near Mexico City. In the 1970s, Sosa Texcoco built the first commercial facility to harvest and dry spirulina, exporting to the USA and Japan beginning in 1979. A section of the lake was channelized in a caracol shape to cultivate naturally growing spirulina, harvested through screens and spray-dried into a powder. Spirulina Mexicana was the world's largest producer through the 1980s, but closed by 1995.

Spirulina Mexicana's Caracol in Lake Texcoco near Mexico City.
Lake harvesting, dewatering and drying spirulina in Myanmar. Courtesy of Min Thein.

Myanmar: Commercial harvest began in 1988 on several alkaline volcanic lakes that enjoy natural spirulina blooms. By seasonally harvesting and processing spirulina from natural lakes, Myanmar Pharmaceutical Industries produces about 150 dry tons of spirulina in 60 days from February to April each year. Dry chips, tablets and packaged products are distributed in Myanmar.

Commercial outdoor pond cultivation systems

Most current commercial farms over the past 30 years have been designed with shallow raceway ponds circulated by paddlewheels. Ponds vary in size up to 5000 square meters (about 1.25 acres) or larger, and water depth is typically 15 to 25 centimeters. They require more capital investment than lake farms, and operate at higher efficiency and quality control.

Earthrise Nutritionals, California, USA: Earthrise was established in 1981 and over the next decade expanded to cover 108 acres. Owned by Dainippon Ink& Chemicals of Japan, by the mid 1990's Earthrise had the world's largest production capacity of 500 tons per year.

Earthrise Nutritionals in Imperial Valley California USA.
Cyanotech on the Kona Coast, Hawaii.

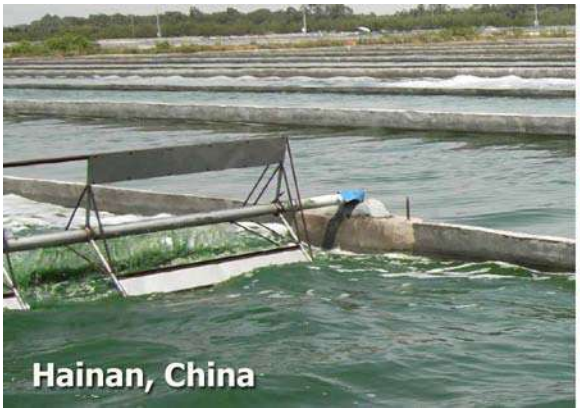
Cyanotech, Hawaii, USA: Cyanotech opened in 1985 on the Big Island of Hawaii with a capacity of 400 tons of spirulina per year as well as haematococcus for astaxanthin for human and animal food supplements.

Boonsom Farm, Thailand: Boonsom Farm near Chiang Mai is a medium size (40,000m2) family-owned spirulina farm, producing finished products for the regional market in Thailand and Asian countries for the past 20 years. Boonsom Farm is promoted as an algae-tourism destination, offering a tour, samples of spirulina foods and a spirulina health spa.

Boonsom Spirulina Farm near Chiang Mai Thailand.
Parry Nutraceuticals spirulina ponds in India.

Parry Nutraceuticals, India: In 1990 India established a national standard specification for food grade spirulina. Parry Nutraceuticals began spirulina production in Tamilnadu in 1996 and expanded into astaxanthin from haematococcus in 2003.

Hainan Island China: Today China has numerous producers, with an annual capacity in the thousands of tons, the world's largest spirulina producer for both the domestic market and a major world exporter.



Some of the largest Chinese spirulina farms are on Hainan Island.
Yaeyama on Okinawa Island, Southern Japan grows chlorella algae in circular ponds.

Taiwan: Various farms have produced several hundred tons spirulina and chlorella per year. Depending the market, some may shift to growing chlorella when its price is higher.

Other farms: There is reported commercial production in Australia, Cuba, Chile, Vietnam, Israel, Bangladesh, Philippines, Martinique, Peru, Brazil, Spain, Portugal, Chad and other countries. Spirulina farms are multiplying around the world.

Chlorella Farms: Many early chlorella farms developed circular ponds. Chlorella is a batch growing and harvest system, unlike the continuous growing and harvesting of spirulina all season long.

Photobioreactors, tubes and tanks

Spirulina grows well in sunny, warm alkaline waters and can be continuously cultivated outdoors in a pure culture. Most other algae are subject to contamination by competing algae and maintaining a pure culture outdoors is far more challenging.

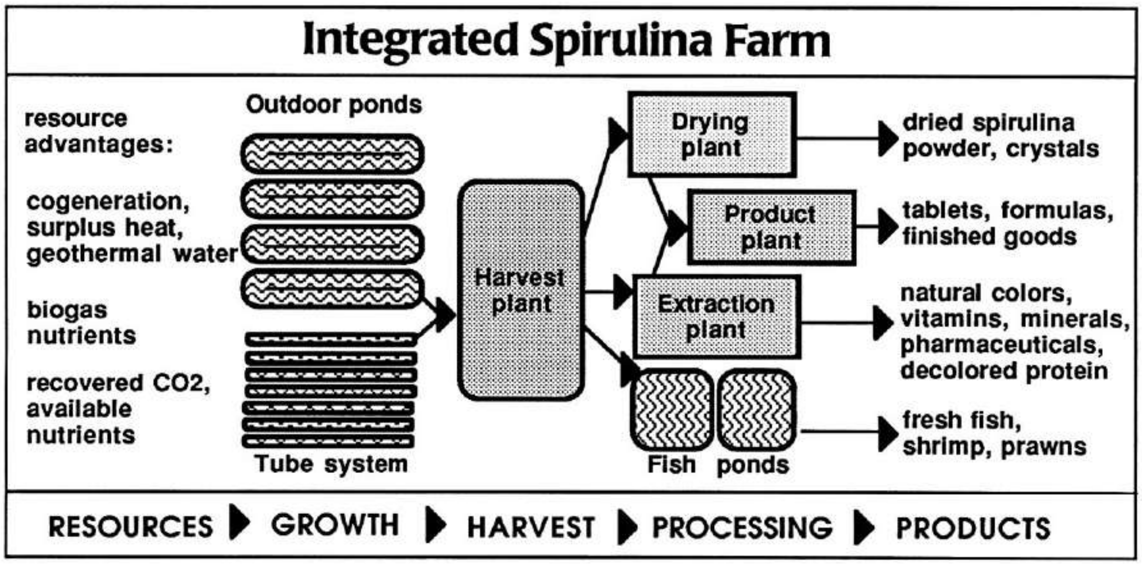
Photobioreactors, tube, plate and tank systems have been developed to grow algae in closed systems in colder climates, to prevent contamination, or grow higher value algae that require more cultivation control. Companies may use bioreactors for high-value algae and their extracts such as chlorella, haematococcus, nannochloropsis, and isochrysis for pharmaceutical, industrial, cosmetic and aquacultural applications.

Because photobioreactors and closed systems have been more costly than open pond raceway systems, they have been considered too costly, not competitive and are not generally used for commercial spirulina production.

Integrated production farms

Current farms designed to produce high quality spirulina have high production costs. To lower costs, future farms need to integrate nutrient resources, refine production systems and produce a variety of end products, from valuable extracts to inexpensive protein.

Future farms may be sited on alkaline lakes where algae grows on natural carbon nutrients. Other farms may locate near oil refineries or industrial centers using surplus industrial CO2 and other nutrients. Hot water from energy plants, or hot geothermal water, may provide heat to grow algae year-round in cooler climates. Still other farms may be co-located next to animal feed lots, digesting and recycling animal waste nutrients to grow algae.



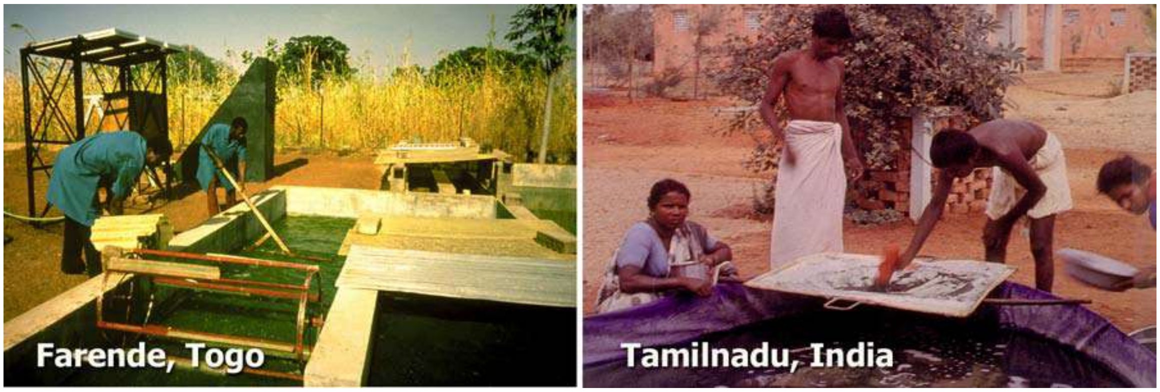
Farms may build integrated aquaculture systems. Fresh wet algae can be added directly to fish ponds or to a dry feed ration. Integrated farms could cultivate a variety of algae, shifting species during warm and cooler seasons, and produce a variety of products. Some may specialize in pharmaceutical compounds, enzymes or medicines. Biochemical plants will make concentrated vitamin, fatty acid and pigment extracts.

Village farms in the developing world

As a supplement, spirulina algae offers remarkable benefits for undernourished people, especially children. Over the past 30 years, numerous projects have been growing spirulina in developing world villages in Africa, Asia and South America.

The Integrated Village System in Farende, Togo. This remote village participated in an experimental appropriate technology project developed by Dr. Ripley D. Fox. Solar panels powered pond paddlewheels. A small 100 m2 pond could supplement the diet of 100 children a day. Pouring pond water through a screen, spirulina became a paste, then solar dried and distributed at the health clinic. Undernourished children took spirulina as a daily. One tablespoon a day mixed with water brought remarkable results.

The design for the Integrated Health and Energy System won the prestigious 1987 European Award for Appropriate Environmental Technology, sponsored by the EEC and the UN Environmental Program.



Tending the spirulina basins in Togo. Solar panels and dryer in back.
Home cultivation and harvesting in a village in Tamil Nadu, India. (Courtesy of C.V. Seshadri).

Family scale cultivation in Tamil Nadu, India. A government sponsored project in Southern India provided small backyard basins to women for family nutrition with the goal to develop into local village networks to combat Vitamin A and general immune deficiency conditions. India has conducted a joint effort with many government agencies covering all aspects of spirulina, from simple cultivation basins to large scale commercial farms. The government has sponsored large scale nutrition studies with animals and humans and has investigated therapeutic uses.

Family and community microfarms

A common request over the past 30 years is "How can I grow spirulina at home or in my community?" Today microfarms are springing up around the world.

Over this past decade, over 50 small spirulina producers have emerged across France, In 2004 a spirulina school was established at the CFPPA Center in Hyères, engaging more people to join this community. In 2010 most of the French producers became members of the Fédération des Spiruliniers de France, an important step towards good practices, HACCP and eventually organic production.

Spirulina Domaine Traverse Greenhouse in the south of France, with products.

French spirulina farmers grow inside greenhouses, typically harvest through screens and squeeze out water, press the thick paste through a spaghetti noodle machine, extruding rows of noodles on sheets that are loaded into solar assisted dryers. Dried noodles can be chopped into smaller pieces, ground using a coffee grinder into granules and powder and pressed into tablets. Noodles and tablets are packaged in bottles or foil packs.

A manual explaining how to cultivate on a small scale is *Cultivez Votre Spiruline (Grow Your Own Spirulina),* available as a free download at algaecompetition.com. The author, Jean-Paul Jourdan, operated spirulina farms in Europe and Africa for many years and has developed low cost, low technology, simple and effective solutions.

Jean Paul Jourdan shows how to harvest, dry and package spirulina grown at his personal microfarm.

Although microfarms may not enjoy the same production cost savings as large scale production, they can make up the difference by selling direct to local clients. A commercial farm producing finished products gets about 35% of the retail price, 65% going to distributors, wholesalers and retailers. A microfarmer, selling direct to the local community can capture up to 100% of the value chain.

Whereas algae biofuel ventures forecast huge production scale to achieve commercial viability, spirulina represents an algae that makes small scale cultivation viable. This opens up the possibility of a future with many small decentralized algae production systems, even in urban and surburban areas.

6. Development of a Spirulina Industry – Marketing

Marketing products around the world

In over 40 countries, tablets, powder and capsules are widely used supplements. Spirulina is a featured ingredient in pasta, cookies, snack bars and juice drinks, and in personal care products like skin creams and shampoos. Look for it in innovative pet supplements for fish, aquatic animals, birds, cats and dogs. Natural food colors from spirulina have been used in Japan for years.

Marketing spirulina products around the world in over 40 countries.

Market evolution in the USA

In the USA, spirulina was introduced in 1979 through natural food stores by Earthrise Company and through network marketing. Natural food customers embraced algae, discovering many ways to use it. Spirulina gathered a small, dedicated and steadily growing following, but remained a long way from mainstream recognition.

In 1981, *National Enquirer* front page headlines announced: *Doctor's Praise: A Safe Diet Pill – You'll Never Go Hungry.* The article claimed spirulina was a safe appetite suppressant. It became an overnight diet phenomenon. Hundreds of diet pill companies jumped on the bandwagon, rushing to market. Within a month, new brands appeared in health food stores, drug stores and supermarkets.

The media hype led a boom and bust cycle. There wasn't enough spirulina to fill market demand. The world supply was about 500 tons per year from Mexico and Thailand. Much of this was sold in Japan, and only several hundred tons per year of real spirulina entered the US market. Many brands sold by diet pill companies were adulterated with alfalfa or cheap green fillers. Much of the public turned away, believing spirulina was little more than a diet fad. Concerned about claims and quality, the FDA took action against algae marketing companies. The spirulina market subsided by the mid 1980s.

Natural food consumers who knew benefits of algae remained faithful. As more people recognized the real health value, demand steadily rose again, along with other green superfoods such as chlorella, aphanizomenon blue-green algae, barley grass and wheat grass. Green superfoods grew in popularity about 30% per year in the 1990s.

Presenting spirulina to the US natural food market, showing an evolution of Earthrise ads and products over two decades: 1981, 1990, 1997.

New spirulina products appeared, formulated with natural herbs, phytonutrients, vitamins and minerals to raise energy levels, boost athletic performance and endurance, promote a lighter appetite and offer antioxidant protection. Meal replacements with spirulina offered chocolate, fruit and vanilla flavors. Companies invented snack bars, pasta, and fruit and vegetable juices.

People became aware that nutraceutical foods have health benefits beyond nutrition, and whole foods with phytonutrients can help prevent disease. As more research on spirulina's health benefits were published, it became even better known. With new dietary supplement label regulations in the 1990s, spirulina products began to display label claims about health, structure and function benefits. This new labeling and health publicity propelled food and herbal supplements into more mainstream markets.

Over this last decade, more spirulina produced in China and India reduced prices across Asia, Europe and North America. Today there may be 1000 tons or more sold in the USA market. Health and dietary supplements may represent about 80%, and 20% as an ingredient in human foods, animal and pet foods, and for extracts. Today, spirulina and other algae are ingredients in thousands of products for food, feed, colors, nutraceuticals, medicinals, cosmetics and personal care, biofertilizers and fine chemicals. Even more innovative algae based products are coming.

Spirulina is an ingredient for nutrition, color or functional effect in many international products: crackers, noodles, pasta, cereal, supplements, nutrition drinks and bars.

USA regulatory status and issues

Food*:* American grown spirulina produced by Earthrise and Cyanotech has GRAS Status (Generally Recognized as Safe), based on review of the published information on the safety of spirulina and on a description of their GMP and Quality Assurance Program and US Food and Drug Administration (FDA) review. Spirulina is regulated as a food and dietary supplement. In 1994, the U.S. Congress passed the Dietary Supplement Health and Education Act (DSHEA). Dietary supplements, like spirulina, are allowed to make health statements about the structure and function of the body on product labels based on scientific evidence.

Feed: As an animal feed supplement, spirulina does not yet have an AAFCO (Association of American Feed Control Officials) ingredient description, meaning it should be used in feed applications which are low priority enforcement. Since spirulina is already GRAS, AAFCO status should be achievable.

Food Colors and Additives: The US FDA regulates food colors and additives and requires a long and expensive approval process before natural colors can be used in foods and cosmetics, making it difficult for natural colors to replace chemical food dyes.

Natural colors for foods and cosmetics

Spirulina contains 10-20% phycocyanin making it the best natural blue color for foods. Blue, red and yellow are the three primary colors, and blue is used to make other colors. In Japan, food regulations mandate the use, of natural food colors without chemicals or preservatives. Dainippon Ink & Chemicals developed a food color from spirulina called Lina-Blue®, used in chewing gum, ice cream, popsicles, candies, soft drinks, dairy products and wasabi, the green colored hot paste served in sushi bars. Another form is made for natural cosmetics.

Spirulina blue pigment phycocyanin is a food color for gums and candies.
Algae is an ingredient in many personal and body care products.

A specialty food for fish, birds, animals and pets

Demand is surging for specialty aquaculture feeds that increase growth rates and disease resistance for farmed fish and prawns. Tropical fish, ornamental birds, animals and pets of all kinds consume a portion global spirulina production.

Fancy koi carp. Highly prized fish with distinctive bright red, yellow, orange, white and black markings are often seen in ornamental pools and fountains. Many koi feeds have 5 to 20% spirulina for its rich carotene pigments that enhance red and yellow patterns, while leaving a brilliant pure white. This clarity and color definition increases their value.

Popular fish foods for koi and colorfish and many aquarium foods contain spirulina.

Popular for aquaculture grown products. The fish farming industry is growing each year. Adding spirulina to fish feeds helps solve the two biggest problems. First, farmed fish are susceptible to infection and disease. Second, the flavor, texture and skin color may be inferior to wild fish. Fish farmers have discovered five key benefits to using spirulina to improve cost/performance of fish feeds: 1) better growth rates, 2) improved quality and coloration, 3) better survival rates, 4) reduced medication requirements, 5) and reduced waste in the effluent.

Improves survival of fish fry and brine shrimp. Aqaculture fish are grown from tiny hatchery fry. Often, survival rates are very low. Spirulina added to the feed ration at 1 to 10% levels increases survival rates, allowing fish to reach market size sooner. It is the best food for tiny brine shrimp, sold in pet stores as a popular food for aquarium fish.

Health food for aquariums. For many species of exotic tropical fish, algae are an essential part of the diet. Spirulina promises five benefits for healthy aquarium fish: 1) great profile of natural vitamins and minerals, 2) rich in muco-proteins for healthy skin, 3) phycocyanin for reduced obesity and better health, 4) essential fatty acids for proper organ development, 5) rich in natural coloring agents such as carotenoids. Feeding will result in beautiful, healthy and longer-lived fish.

Health, beauty and color for ornamental birds. Zoos feed flamingos and ibis a diet rich in spirulina, and report improvement in health and color. Algae increases feather color and shine, healthy beaks and skin, and promotes good bacteria in the digestive tract. Pet birds can be more beautiful, healthier and live longer.

Enhanced fertility for bird breeders. Canary, finch, parrot, lovebird and other breeders use spirulina to increase coloration, accelerate growth, sexual maturity and improve fertility rates. Ostrich and turkey breeders use it to increase fertility and reproduction rates. It enhances desirable yellow skin coloration in chickens and increases the deep yellow color of egg yolks. Studies with chickens suggest that adding a small percentage in the diet stimulates macrophage production, improving immune performance and disease resistance without side effects.

Healthy food for cats and dogs. For healthy skin and lustrous coat, spirulina is good for cats and dogs, for nursing mothers, bottlefed kittens and puppies. Appetites of finicky cats perk up with a little sprinkled on their food. Owners report spirulina fed pets have a fresher breath odor.

Tonic for horses, cows and breeding bulls. Owners of highly valued racehorses use spirulina in their feed ration for faster times and recovery, but trainers tend to keep results secret. Dairy farmers use it to keep cows healthy by improving intestinal flora that is so important in ruminants. Reports have circulated that it increases the sperm count of breeding bulls and fertility in females.

Future expansion of spirulina products

As with other algae, spirulina will be specially grown and adapted to deliver a higher content of desired phytonutrients such as valuable pigments, polysaccharides and lipids for high value nutraceutical and pharmaceutical products. These classes of products will face higher regulatory hurdles than selling algae as a food or food supplement.

The most significant product and market expansion will come as algae production costs fall significantly this decade. Companies seeking to drive down costs in search of commercial biofuel from algae will develop new systems and technologies, introducing lower cost algae products for the food, feed and specialty product markets.

7. The Future of Spirulina in an Evolving World

Understanding the role of microscopic algae, the foundation of life, can help us develop restorative models of personal and planetary health. Algae is an essential part of Earth's self-regulating life support system. Innovative schemes and dreams using algae promise to help regreen the desert, refertilize depleted soils, farm the oceans and encourage biodiversity. Coming soon is a significant lowering of production costs, leading to a wide variety of algae products.

Big investments in algae biofuel will grow our future food and its own bio-packaging

Algae Food and its own bio-packaging.

Today, algae has been called the *'biofuel of the future.'* Over 30 years ago, spirulina algae was called the *'food of the future'*. But until now, production costs have remained high due to a combination of these factors: using agricultural land, fresh water, clean nutrients, skilled personnel, servicing big investments for pond systems, harvesting and drying infrastructure, and complying with food and quality regulations.

With production costs over $10 per kilo, growing algae is still ten times the cost of many commercial foods and feeds. Annual world microalgae output may have reached 10,000 tons of *spirulina*, *chlorella*, *dunaliella* and *hematoccocus*. Even big commercial algae farms are relatively small, less than 100 hectares in size.

Nevertheless, the number and variety of high value food and specialty products from algae has flourished. Today, algae is an ingredient in thousands of products for food, feed, colors, nutraceuticals, medicinals, cosmetics and personal care, biofertilizers and fine chemicals.

Algae are in more products today than you know.

The shakeout in algae biofuels is good for the algae industry

Algae ventures have successfully raised millions for research and development for algae biofuels based on early promises. To deliver competitive algae biofuel, companies will need to crush costs lower than $1/kg! Will they be able to deliver algae biofuels, within this decade, that are cost competitive with conventional fuels?

So far algae biofuels have been an engaging and expensive R&D project. The challenge of scaling up to demonstration projects begins now. Funding required for demonstration scale up is huge, and the lack of access to funding will amplify the shakeout.

Watch these pathways unfold in the shakeout as the algae industry moves toward more realistic, sustainable business models.

• Those ventures with access to deep financial backing from big oil or government funds, and with technology that works, will be prepared to stay the course and produce biofuel products.

• Some high profile ventures are already repositioning their business model to develop more valuable and more immediate ‘co-products’ from algae. Two years ago, many ventures had dismissed co-product markets for algae food and feed products as ‘niche’ markets.

• Other ventures who realize they can’t make it all the way to biofuel commercialization will license or sell off assets such as algae research, cultivation knowhow, intellectual property, technology or system design or components.

• Some big venture partners will bail. The executive decision will be: “had a good look, got some good green press, but now we are cutting our losses and moving on to more immediately profitable opportunities.”

• Other ventures will continue with smoke and mirrors, touting their secret sauce, proprietary IP or GMO breakthrough to keep grabbing R&D funds or government grants. They operate on the hope that they can sell out to bigger fish before the world perceives they have no clothes.

• More ventures will shut down. Surviving ventures will pick off infrastructure, technology and personnel, like carrion birds feasting on a carcass.

The scramble intensifies for algae ventures to show how their business model can actually produce algae at a reasonable cost for markets that are real and immediate. Many smart algae biofuel companies will be redirecting their finite financial resources toward more immediate income streams from algae products if they are to survive in the shakeout.

Big investments in algae biofuels are bringing big benefits. Breakthroughs from understanding algae cultivation and new technology and systems innovation will dramatically lower algae production costs and open new markets for higher value algae food and feed products. We are entering a very exciting time for algae business development.

Algae food and bio-plastic products are likely to arrive before fuel, one of the least valuable end products. We'll see healthy algae omega 3 oils and protein food and feed products, improving our diets, and algae based resins, biopolymers and bioplastics replacing fossil fuel chemical products.

How will algae production costs come down?

Innovations and breakthroughs will change the way algae has been produced for 30 years. How? Largely through biomimicry- better understanding how nature works.

• **Discover better performing algae cultures.** With big R&D budgets, scientists can screen, identify and engineer strains of algae with superior properties, faster growth rates, and ability to grow in low light and temperature and high saline, brackish or ocean water.

• **Develop simpler design and technology**. Rethink, redesign and reengineer growing, harvesting, processing and drying to reduce capital costs for equipment, operating costs and power use.

• **Use marginal land and water just like nature.** To grow on the large scale needed to produce biofuels, find remnant flat land and ocean, saline, brackish or waste water located near nutrient resources.

• **Use waste nutrients just like nature.** To lower costs, recycle waste CO_2 effluent, animal and plant wastes, which are costly problems today. Ferment agricultural, animal, industrial and waste streams into carbon, nitrogen, phosphorus, potassium and trace nutrients to feed the algae. Or grow algae by cleaning up municipal waste.

• **Use all the algae biomass just like nature.** Start with the end product and work backwards. What products can be sold, for how much, and how will markets be developed for those products?

• **Create multiple revenue streams to offset costs**. Environmental services may include CO_2 and pollution mitigation, wastewater treatment, biomass and waste heat for electricity and carbon offsets. Non-fuel algae products may represent the 70% of the biomass. Potential revenues include algae oil and lipid supplementation for animal feedstocks, biofertilizers, fine chemicals and bio-plastics, extracts for pigments nutraceuticals, pharmaceuticals and medicinals.

• **Exploit the unexpected- carpe diem**. Investment drives innovation and creates breakthroughs. Who knows what will unfold that we haven't thought of yet.

Adapting spirulina for more growing conditions and applications

A dazzling array of new products are coming from algae. Spirulina will lead the way. Why? Spirulina has four advantages over other microalgae: 1. Proven safe. 2. Easy to grow. 3. Easy to harvest. 4. Ongoing scientific research on health and medical benefits.

The scientific documentation of health and medical benefits will keep spirulina among the most popular algae. For humans, new breaking research this year shows spirulina enhances immune functions for people over 50 years old. For animals and fish, USDA will soon be releasing new data on the value of spirulina.

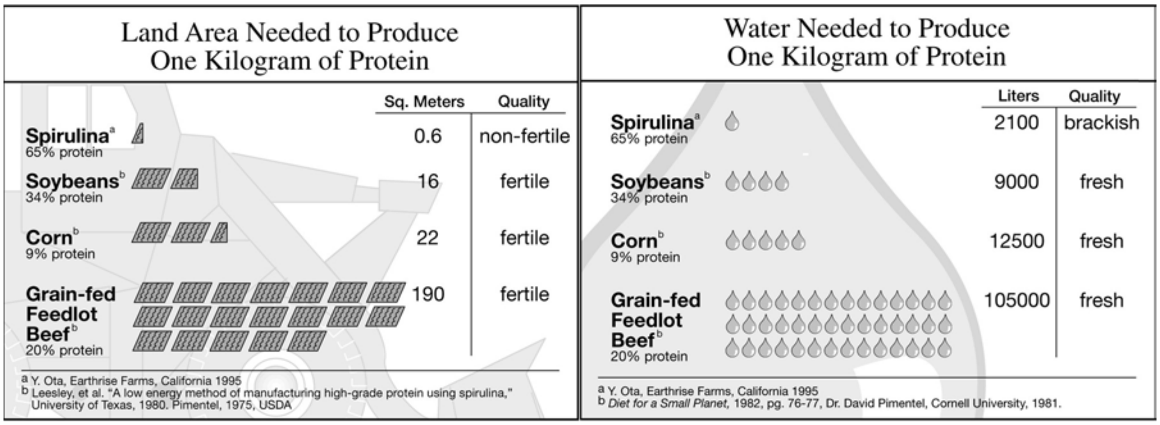
Spirulina, like other blue-green algae, lends well to adaptation and hybridization, even without resorting to genetic modification. Developing cold weather tolerant spirulina strains will both expand the length of the growing season and the geographic range to more temperate and colder regions. Salt tolerant spirulina will allow the use of abundant salt or seawater. Spirulina adapted to produce a high lipid content such as DHA or EPA could be a valuable Omega 3 source for humans, animals and fish.

Farming alkaline lakes and greening desert coastlines

Spirulina lakes are found in Peru, Chile, Myanmar, Australia and stretch across the Sahara and East Africa, near millions of undernourished people. For 20 years, scientists and visionaries have proposed harvesting algae from lakes in Ethiopia and Kenya.

The best approach is using cultivation ponds beside these lakes, without disturbing the larger ecosystem and the flamingos of the African lakes. They are a tourist attraction, contribute to lake ecology, and should be protected. A project sponsored by governments, international agencies and business could distribute algae to local people. Farming East African lakes could create opportunity as a new food for Africa, relieving pressure on food growing areas, and providing an export crop

Once scientists learn to successfully cultivate seawater tolerant spirulina, new food growing areas can use 10,000 miles of accessible desert coastline in hot climates: Mexico, Peru, Chile, West, North and East Africa, Egypt, Arabian peninsula and India.



Spirulina has big resources advantages over conventional food and meat production. Land and water needed to produce spirulina protein is much less.

Conventional food production hides environmental costs and consumes natural resources. We pay for these externalized costs, but not at the cash register. Spirulina has few hidden environmental costs and offers more nutrition per acre than any other food. It conserves land and soil and uses water and energy more efficiently per kilo of protein than other foods. As global algae production expands using non-fertile land and brackish water, more cropland can be returned to forest and we can regreen our planet.

Microfarms for family and community cultivation

Over the past 30 years, many people have asked they can grow spirulina themselves in their own back yard. In France there are about 50 spirulina microfarmers and a school curriculum for growing algae. Growers are producing their own products and selling directly in the local region.

French microfarms: Spirulina de Savoie and Spirulina de Provence.

Soon, remote sensing devices and cell phone apps will assist the basic functions of culture health monitoring and diagnosis. Growing food in cities and urban areas may become critical as fuel costs rise, making transported food increasingly expensive. On a small land area, a community could meet a portion of its food requirements from microalgae, freeing cropland for community recreation or reforestation.

Unlike plans for algae biofuel that envision mega farms, spirulina can be produced on a small scale. New technologies and systems design will make microfarming less costly, easier and more accessible for even more people around the world. Ecological communities can combine algae production and aquaculture with organic gardens.

Abundance from sharing knowledge and local algae production

Algae can create a future of abundance by offering affordable, locally produced food and energy for ecological, healthy living. Family or community scale abundance microfarms can enhance the health, nutrition and quality of our future life.

Sufficient knowledge about algae production exists today to support successful cultivation. Unfortunately, much of the best knowledge rests with scientists and entrepreneurs who must sequester their research findings due to intellectual property limitations. The algae industry today is fractured as each company acts to protect intellectual property behind a wall of secrecy. Scientists are prevented by non-disclosure agreements to collaborate with others or share production breakthroughs. Secrecy leaves students, researchers, press and policy makers without the most up-to-date knowledge. This degree of secrecy tends to concentrate rather than expand knowledge, slowing innovation.

The 2011 International Algae Competition (www.algaecompetition.com) was initiated as an open source collaboratory to expand a vision for algae in our future. Its objectives are to encourage and share design ideas and best practices for algae production systems, elevate awareness for algae growing systems in backyards, rooftops, vacant lots, public spaces, villages, and promote a healthy and sustainable future for integrated living communities.

AlgaeCompetition.com website

Microalgae, like spirulina, are essential resources for individual and planetary health and restoration. The oldest photosynthetic life form is back. It represents a return to the origins of life.

Adapted from "Spirulina World Food- How this micro algae can transform your health and our planet." by Robert Henrikson © 2010. Available at Amazon.com.