Clean Techn Environ Policy (2011) 13:431–445
DOI 10.1007/s10098-010-0321-5

REVIEW

Water global recourse management through the use of microalgae addressed to sustainable development

Armen B. Avagyan

Received: 10 November 2009 / Accepted: 14 September 2010 / Published online: 21 October 2010

Abstract Cost advantages are the primary drivers for water resource management friendly investments. Therefore, acceleration of sustainable development requires the implementation of new innovation approach. At present, preventative measures of algal bloom development are not achieving sustainable results and spread of the blue-green infection can reach catastrophic dimension. Our vision of water recourse management includes the use of bloom and wastewater cleanup microalgae biomass aimed at supplying biofuel manufacturing profitably and boosting feed, biopharmaceuticals, etc., manufacturing in cost effective manner. Microalgae must be the key tool for the new design and building sustainable development of life and water resource management. Offered sustainable development business model, convenient for policymakers and companies, will make global goal of bioculture fully achievable as well as makes it imperative for the world to devise an international response and a plan of action.

Keywords Sustainable development · Water recourse management · Algal bloom · Water bodies restoration and conservation · Wastewater cleaning · Microalgae · Biofuel · Feed additives

Introduction

The patterns of water, nutrient, and energy cycles in the biosphere have been established in course of many million years of biological evolution. These cycles have been degraded in exponentially accelerating pattern during the last 100 years, by human activities mostly due to the lack of environmental consciousness, knowledge of how to establish sustainable systems of water resources management and mechanistic approach to the management of water resources (WDR 2008; UNESCO 1998; EEA Report 2009). Water is a fragile resource that is quite different from ore and oil deposits. It is at once renewable through the natural cycle, yet if spoiled or over-abstracted, it actually becomes non-renewable. The global water withdrawal will increase by 31% between 1995 and 2020. Over the last 50 years, he has quadrupled while world population doubled (Clarke 2003). Currently, about 1 billion people around the world routinely drink unhealthy water. Climate change would also lead to increased water stress, which by 2020 could affect 75–250 million people in Africa alone (Pachauri 2009).

Eutrophication of water bodies, the processes through which the flux of growth-limiting nutrients from watersheds to receiving waters stimulates excessive plant growth such as freshwater and marine algal blooms, continues to increase (Hudnell et al. 2008; Lopez et al. 2008; Hudnell 2010a, b). When such populations are subjected to suboptimal conditions, they respond by increasing their buoyancy and move upward nearer to the water surface (SWCSMH 2007). The global increasing occurrence of blue-green cyanobacteria harmful algal blooms (HABs) over the last 60 years has been linked to the process caused by the enrichment of water with nutrients from human population growth and associated activity and these

---

Electronic supplementary material The online version of this article (doi:10.1007/s10098-010-0321-5) contains supplementary material, which is available to authorized users.

A. B. Avagyan (✉)
Research and Industry Center of Photosynthesising Organisms, Feed Additives and Physiologically Active Compounds, Yerevan, Armenia
e-mail: armin.av@hotmail.com

problems know no national borders and create great nuisance in the management of freshwater bodies worldwide (Kann and Falter 1985; UNESCO 1998; Cronberg et al. 1999; Cosgrove and Rijsberman 2000; Clarke 2003; Ramsdell et al. 2005; Biological Controls 2006; Fristachi and Sinclair 2008; Lopez et al. 2008; Griffin 2009, EEA Report 2009; Hudnell 2010a, b). Whereas 30 years ago, the HABs problem was scattered and sporadic; today, many countries throughout the world are increasingly impacted by the growing environmental problem of HABs, and we have more clearly defined the extensive boundaries of this problem. If no countermeasures are taken, anthropogenic assault will gradually lead to a situation when water is no longer the source of life, human and ecosystem well-being, but on the contrary, a source of disease, ecosystem disruption and social disorder. An important consequence of this process is the general reduction in the possibility of water use and the increasing importance of lakes and other water reservoirs; consequently, many resources for socio-economic development can be seriously damaged.

The Municipal Water Supply-Efficiency Requirements Act and the U.S. Safe Drinking Water Act direct DOH to conservation and restoration of drinking water supply. The EU Water Framework Directive requires the 'promotion of sustainable water use based on a long-term protection of available water resources' (EEA Report 2009).The alarming rate of increase in HABs signals the need for an evaluation of surface-water management and restoration policy, and identification of methods for reversing eutrophication trend, if we are to have a sustainable supply of usable freshwater (Hudnell 2010a, b).

Cost advantages are the primary drivers for water resource friendly investments. Therefore, sustainable development requires the implementation of new innovation management approach in the novel ways and technology and innovation will remain at the heart of success. Thus, our ripening into maturity and survival will depend on our ability to assimilate the explosive progress of technology and environmental management tools towards a new culture—bioculture as a global societal shift toward a business activity and lifestyle—webbed with unifying values and based on the better understanding requests of bios. This should provide the opportunity to see the future in a new vision, where they can serve as a revelation of the truth and where every endeavour is governed by reflection on and appreciation of the environment. If aquatic resources are to be exploited on a sustainable basis in the future, a concerted effort is needed to resolve the conflicts between user groups including sustainable manufacturing. In this case, the use of sun microalgae may be the main future resource for development of Global Life Conserve Industry (GLCI) as well as for water resource management and Life sustainable development. The gravity of the problem increases in the face of drinking water source degradation.

Therefore, this article presents situational analyses by the use tools of system and synthetic biology, for identification water resource management strategy in the framework of our concept addressed to global sustainable development through including microalgae and its biomass in Production (such as wastewater treatment and biofuel manufacturing) and Bio Cycles (through food, feed, pharmaceuticals, perfumery production etc.) (Avagyan 2008a).

Discussion

Harmful algal bloom and threats

Properties

Blue-green cyanobacteria of bloom are a group of prokaryotes whose history goes back to 2.7 billion years. Cyanobacteria are not true algae. They have no nucleus—the structure that encloses the DNA, and no chloroplast—the structure that encloses the photosynthetic membranes, the structures that are evident in photosynthetic true algae. More highly evolved organisms typically outperform their predecessors in the battle for survival. Eukaryotic green algae, the base of the aquatic food web, evolved from prokaryotic cyanobacteria between 2.5–1.0 billion years ago. Green algae predominated over cyanobacteria until recently. The excessive input of nutrients into water due to human activities increasingly enables toxigenic cyanobacteria to outperform and replace green algae. Therefore, blue-green algae tend to dominate in lakes with a low N:P ratio by weight and blue-green algae are favoured and displace true algae (Kann and Falter 1985; Gross and Pfiester 1988).

The taxonomy of cyanobacteria, often imprecise, is currently under a state of revision (Fristachi and Sinclair 2008). Many cyanobacteria have not yet been characterized (Afsar and Groves 1995; Ramsdell et al. 2005; SWCSMH 2007; Lopez et al. 2008, Fristachi and Sinclair 2008; Warrington 2009). The majority of cyanophytes are aerobic photo-autotrophs, their life processes require only oxygen, light and inorganic substances. In fact, many blue-greens have higher temperature optima than eukaryotic algae of the same water, with temperature optima for some of the bloom-forming species probably in the 25–35°C range and require a temperature higher than 15°C for incipient photosynthesis. Therefore, there is a characteristic seasonal succession of the bloom-forming species, apparently due to their differing responses to the physical–chemical conditions created by thermal stratification (WBGA 2009; BGADAT 2009; Warrington 2009).

The very potent toxins produced by many solitary, filamentous or colonial aquatic cyanophytes are responsible for an increasing number of water-related poisonings of both wildlife and people worldwide and can cause serious difficulties to water suppliers (Lopez et al. 2008; Fristachi and Sinclair 2008; Warrington 2009; BGADAT 2009). The U.S. Environmental Protection Agency included cyanobacteria and their toxins on the first Candidate Contaminant List (CCL 3) in 1998. This list includes organisms and chemicals selected on the basis of their potential public health significance and general unavailability of occurrence data and other relevant information. Cyanobacteria and their toxins were included in the CCL 3 for two reasons, namely that (1) they are not necessarily associated with faecal contamination, and, therefore, will not be adequately controlled by provisions of either the Surface Water Treatment Rule or the Enhanced Surface Water Treatment Rule, and (2) they may not be adequately removed from drinking water by conventional water treatment techniques. Listing these organisms in the CCL 3, therefore, will focus attention on them and make them a priority for research to determine what triggers toxic algae growth in source water and the effectiveness of water treatment practices.

The chemical structures of blue green algae toxins are bewilderingly complex and have proven to be exercises in structural elucidation and subsequent synthesis that have occupied chemists for many years (Fristachi and Sinclair 2008; Warrington 2009). The three most common cyanotoxins are described chemically as cyclic peptides, alkaloids, and lipopolysaccharides (LPS). Cyanotoxins can be classified according to their chemical structure or organs of their affect (Warrington 2009). According to this approach, neurotoxins affect the nervous system, hepatotoxins attack the liver and dermatoxins irritate skin and mucous membranes. The neurotoxin alkaloids produced by *Anabaena flos-aquae* (manufactures anatoxins) and *Nodularia spumigena* are fatal at 20 μg per kg body weight, and anatoxins, aphantoxins of *Aphanizomenon flos-aquae* leading to paralysis of muscles needed for breathing. Most of the recorded toxic blooms are caused by *Microcystis aeruginosa*, which manufactures hepatotoxin microcystin, which are fatal at 9 μg per kg body weight. These are roughly equivalent to 1/20000 and 1/10000 of an ounce of toxin or about the same potency as cobra venom. Some cyanotoxins, like cylindrospermopsin, affect multiple organ systems. The World Health Organization has a limit on the toxin Microcystin at one part per billion (ppb). It was set at a level considered to be safe for human consumption (Veldhuizen 2009). Some toxins are tumor promoters and oncogenic in lab animals, other species of blue-green algae produce chemicals that taint drinking water with musty or earthy tastes and odours (BGA 2008). These off-tastes and odours require extensive treatment to remove and in severe cases make the water undrinkable.

Impact on health

Freshwater HABs can similarly affect the perception of freshwater and marine waters safety, impacting decisions by consumers and public utilities (Fristachi and Sinclair 2008; Lopez et al. 2008; Hudnell 2010a, b). It is expected that the risk from HABs to drinking and recreational waters will increase with increased stress and demand on those systems (Fristachi and Sinclair 2008). The U.S. researchers tested 81 different lakes (Lake Erie, Lake Ontario, Oneida Lake, Lake Champlain, etc.), scattered across New York State (Boyer 2008). Testing proved that 20% of them had some indication of potentially toxic blooms. Most of these Lake Champlain toxic samples were collected from the eutrophic Missisquoi Bay region which is characterized by high phosphorus inputs and expansive *Microcystis* blooms during the summer growing season. The samples collected from Lake Erie and Lake Ontario, Oneida Lake with its well-established HABs exceeded the WHO advisory limit of 1 μg l^{-1} (Boyer 2008). Western Lake Erie has a new form of toxic, blue-green algae and it is a hardy one that hugs the shoreline (Henry 2009). The blue-green algae content was obtained in 18 lakes of Oregon (Veldhuizen 2009). Microcystins were detected in 85 of 87 tested samples and 63 samples (72%) contained concentrations >1 μg per g. Through HPLC and ELISA tentatively identified microcystin-LR, the most toxic microcystin variant, as the predominant congener (BGADAT 2009). In both the Eagle Creek and Geist reservoirs, the detection of blue-green algae microcystin toxin resulted in recreational usage advisories being posted by the Indiana State Department of Health (Warrington 2009). Further, a review of blue-green algae research throughout the Midwest indicates that blue-green algae blooms and the occurrence of algal toxins, especially microcystins, become increasingly common in midcontinent lakes and reservoirs. In Indiana, it have been documented cases of blooms of potentially toxic blue-green algae in several areas since 2001, which included Ball Lake in Steuben County, Lake Lemon, and Monroe Reservoir in Monroe County, and in 20 other lakes and reservoirs state-wide, served as drinking water supply reservoir for Bloomington and surrounding communities. In Washington State, staff responded to a citizen's call about bloom on Lake Sammamish (Warrington 2009). A beach on Pewaukee and other Nebraska Lakes was closed due HABs (Walker et al. 2008; DeLong 2009).

Human diseases, ranging from minor rashes and other allergic reactions to gastroenteritis and even more severe illnesses, are known to result from contact with affected water during recreational activities (Falconer 1999; Pitos et al. 2001; Fristachi and Sinclair 2008; Lopez et al. 2008). The frequently occurring 'swimmers itch' is attributed to contact with *Lyngbya majuscula*, *Schizothrix calcicola* and *Oscillatoria nigroviridis*, which are commonly found in tropical and subtropical seawaters. Some symptoms include redness of the skin and itching around the eyes, sore red throat, headache, diarrhoea, vomiting and nausea, gastroenteritis, hepatoenteritis and long term chronic effects such as liver damage or tumour promotion when exposure to the toxins is prolonged (BGA 2008; Pitos et al. 2001; Henry 2009; Miami 2009).

The Table 1 presents official dates of known human exposures to cyanobacterial toxins (up to 2000) (Miami 2009). In Brazil, 26 of 75 kidney dialysis patients were killed in 1 day when cyanophytes bloomed in the reservoir that supplied the water used in the dialysis machines (Warrington 2009). It may be difficult to make a confident diagnosis of all cyanophyte poisoning, since the clinical signs and post-mortem findings resemble a variety of other diseases (Warrington 2009). The large amount of liver disease that had previously been attributed to alcoholism may actually have been due to microcystins in the water. A survey of municipal water sources in the U.S. revealed that freshwater cyanophytes producing both nerve toxins and liver toxins accounted for some of estimated 900,000 illnesses and 900 deaths every year due to contaminated drinking water (Warrington 2009). A severe algae outbreak left tap water undrinkable for a week for half of the 2.3 million residents in Wuxi, a city in the eastern Jiangsu Province (China 2007). In Australia, people drinking water from an affected reservoir had elevated levels of certain liver enzymes (Warrington 2009). On one occasion in 1979, the reservoir was treated with copper sulphate by the responsible authorities to kill the algae which, upon death, released their toxins into the water. A week later about 150 people, drinking from the water supply, fell ill, and many ended up in the hospital. They showed evidence of gastrointestinal, liver and kidney affected, with no evidence of any causative virus or other pathogen (Warrington 2009).

Some impacts of blooms may be direct, including possible effects of toxins on fish, invertebrates, and other aquatic fauna, or indirectly, including a reduction of submerged plants when plankton biomass becomes very high, and changes in fish community structure if summer cold water refuges are lost due to hypolimnetic anoxia (WHO 1999; Ackefors et al. 1990; Xue-jun and Ping 1997; Frank et al. 1998; FAO 1998; Barros et al. 2001; Pitos et al. 2001; Warrington 2009; Hudnell 2010a). Concerns about cyanophyte toxins contaminating eggs and carcasses in intensive poultry farms have led to the extensive use of environmentally undesirable pesticides to control blooms in farm water supplies (Warrington 2009). The risks humans run by eating fish and other animals from contaminated waters are difficult to quantify but are significant (Warrington 2009). It is unknown which plants actually take up the toxins (Warrington 2009). There is no such protection in place for the irrigated agriculture and aquaculture industries. HABs are sprayed on crops producing cyanotoxin-containing aerosols that may be inhaled by humans and other animals and absorbed by crops (Hudnell et al. 2008). With leafy vegetables such as lettuce cause special problems, since contaminated water can collect between the leaves. However, it is known that some toxins persist in dried form for several months (Warrington 2009). Freshwater aquaculture is also at risk from cyanophytes, since little or no monitoring for toxins is conducted routinely. Freshwater mussels, for example, accumulate sufficient toxins within 5 days of feeding on *Anabaena* to exceed national food guidelines for contaminated shellfish (Warrington 2009). Cleaning sea foods in many cases will not remove the toxins. Cooking does not destroy the toxins. We do know that many toxins

Table 1 Reported human outbreaks associated with cyanobacteria

Year	Location	Population affected	Exposure route
1930–1931	West Virginia	9,000/60,000	Unknown
1959	Saskatchewan	12 People	Swimming
1960–1965	Harare, Zimbabwe	Children	Drinking water
1975	Sewickey, PA	62% of 8,000	Drinking water
1979	Palm Island, Aust.	139 Children	Drinking water
1980–1981	Pennsylvania/Nevada	>100 People	Swimming, water skiing
1989	Staffordshire, UK	18 Recruits ill	Swimming, canoeing
1992	Outback Aust.	Unknown	Drinking
1992	River Murray, Aust.	26 people	Drinking
1994	China	High rates liver cancer	Drinking
1996	Caruaru, Brazil	63 deaths	Dialysis

are extremely persistent in the environment, often being resistant to chemical or bacterial degradation.

Animal health risks from HABs are much easier to define than risks for humans as animals are more likely to come in contact with cyanotoxin-contaminated water. Blue-greens poisoning has caused the death and liver damage of cows, swine, sheep, dogs, births, etc. (Cronberg et al. 1999; Pitos et al. 2001; Warrington 2009). *Microcystis* occurs widely in Australia and has caused many cases of livestock poisoning in New South Wales and Victoria (Warrington 2009). The other common cyanophyte in the rivers and lakes of the Murray-Darling Basin is *Anabaena circinalis* which was the cause of the big Darling River bloom in 1990–1991. Many sheep and cattle died along the river and samples of the *Anabaena* containing the same paralytic poisons as those present in shellfish PSP toxicity were found in the water (Miami 2009; Warrington 2009). Whether the animal survives the poisoning or not depends primarily upon the concentration of toxin ingested. Surviving animals show photosensitivity, sunburn that is restricted to white areas of cattle and the nose and ears of sheep. Photosensitivity around the mouth can affect feeding and the condition of stock. It has been observed that dairy cows and sheep do not drink water containing toxic algal blooms, resulting in sudden decreases in milk production and deaths. Scouring has also been recorded in poultry, where it leads to a reduction in egg production. A toxic strain of the cyanophyte *Cylindrospermopsis*, which accounts for up to 90% of the phytoplankton in Lake Griffin, FL, is the possible cause for the recent large number of alligator deaths (Warrington 2009).

Ecosystems

Many lakes have extensive littoral areas, and the production of organic matter by these zones is very significant in the cycling of nutrients and in the nutrition of lake organisms. In particular, the large annual production of rooted plants and attached algae may be a major source of decomposing organic matter, and thus nutrients, to the open water and to the sediments of the hypolimnion (Biological Controls 2006; Hudnell 2010a, b). Not only are the sediments of the littoral zone the source of nutrients for these rooted plants, the plants may release nutrients to the water column via aerobic decomposition. Even this expensive process, while necessary, may be insufficient to produce immediate and long-lasting effects, due to internal recycling of nutrients and the associated production of algae and macrophytes (Biological Controls 2006). Nowadays, the most important problem to solve concerns the following question: how to restore and adapt the hydrological, biogeochemical and biological cycles to the new conditions of high population density and activities, without obstructing development (Cosgrove and Rijsberman 2000; Clarke 2003; Ramsdell et al. 2005; EEA Report 2009; Hudnell 2010a, b). A first priority of the U.S. researchers plan for the coming years is to understand and mitigate impacts of HABs species on pelagic and benthic food webs and their capacity to support fisheries and ecosystem services as well as mitigation of bloom impacts of all types using a suite of practical strategies to protect and utilize threatened resources, as well as to directly intervene in bloom development (where appropriate) using economical and environmentally acceptable methods and mitigate impacts of blue-green algae species on pelagic and benthic food webs and their capacity to support fisheries and ecosystem services (Ramsdell et al. 2005; Hudnell et al. 2008; Fristachi and Sinclair 2008; Lopez et al. 2008; Hudnell 2010a, b).

Lake Sevan (max. length 78 km, max. width 56 km, surface area 940 km^2, 1360 km^2, 95 m deep, perimeter of 260 km, and water volume 58 km^3) is Armenia's largest lake, greatest lake of Caucasus Region and one of the greatest freshwater high mountain lakes of Eurasia and one of the largest and deepest of fresh-water lakes of the world (situated at the altitude 1897.5 m a.s.l. Among high mountain lakes only Titicaca is far ahead by size (8300 km^2), high location (3812 m a. s. l.) and such water quality) with age of 1 million years and provided 80% of drinking and irrigation water of Armenia. All other neighboring great lakes, Caspian (Azerbaijan, Iran, Kazakhstan, Russia, Turkmenistan), Van (Turkey), and Orumiyeh (Iran) are saline. Therefore, Lake Sevan is the only strategic potential source of drinking quality water in the whole Caucasus Region. The Lake Sevan Ramsar Site are supports to the following Ramsar Criteria of Wetlands of International Importance; its basin supports at least 48 species of vertebrates and 48 species of plants included in the Red Data Book of Armenia, i.e. 48% of rare, vulnerable and endangered fauna and 12% of flora; Such kind of plants as *Isatis arnoldiana*, *Alyssum hajastanum*, *Acantolimon gabriljianae* have not been found elsewhere in the world; among fish species, the famous Ishkhan (*Salmo ischchan)* and Beghlu (*Barbus goktchaikus)* are endemic; During the autumn migration, the area receives 10–30,000 waterfowls and supports substantial numbers (until 20,000) of *Anatidae*; Lake Sevan Basin supports 46% of flora and fauna diversity in Armenia (Babayan et al. 2003). Agricultural growth, industrialization, recreation, and other demands in coastal areas pose environmental risk and security difficulties (Babayan et al. 2003; Ivanyan 2003; Wilkinson and Gulankyan 2010). The activity coefficient of phytoplanktonic photosynthesis changed within relatively narrow limits, in spite of significant changes in the concentrations of major nutrients and in the structure and productivity of the phytoplankton and signs of eutrophication and at first alga blooms of the blue-green *Anabaena* were observed in 1964 (Babayan et al. 2003; Sargsyan 2007). Since 1970s, the lake was covered with blue-green algae. Phytoplankton found in Lake Sevan were previously considered unusual, relative to other large lakes in Western Europe, being adapted to oligotrophic (nutrient poor) conditions. Since 1970s, many species such as *Melosira granulata* and *M. islangica* dominated in the phytoplankton community of the lake, but further eutrophication reduced their numbers (although a recent upturn in numbers has been recorded). However, many of these species disappeared during euthrophication of the lake. Indeed, species such as *Anabaena flos-aquae* and *A. lemmermanii* flourished, and contributed to the algal bloom. According to the researchers of Armenian Institute of Hydroecology and Ichthyology, further eutrophication of Lake Sevan may lead to irreversible misbalance of its biodiversity as well as blue-green algae will decrease lake's water quality (Hovhanissian and Gabrielyan 1998). In 2003, Global Ecological Fund and World Bank have been financing Natural Resource Management and Poverty Reduction program that also includes plans for the solution of some of the Lake Sevan's problems (Babayan et al. 2003). The goal of the plan is to improve landscape and biodiversity conservation across the whole area, improve opportunities for sustainable use of natural and biological resources in the area, and increase the effectiveness of protection offered by Lake Sevan National Park, through a review of its management and functioning, but task of recent toxic alga bloom biomass progressive increase was not included and solved.

The problems of ecosystem eutrophication can be done through regulating the aquatic biota through the use of biomanipulation tool. The biomanipulation involves the deliberate alteration of an ecosystem by adding or removing species. Nevertheless, biomanipulation can be used as additional or exclusive measure to improve the quality of stagnant waters (Krasprzak 1995; Kasprzak et al. 2002). Food webs are controlled by resource limitation ("bottom-up") and by predation ("top-down"). In the last years, many experiments have been carried on applying gradually of biomanipulation techniques, following a step-by-step procedure aimed to produce a less stressing effect and to have the possibility to modify at any moment the intensity and the direction of the intervention. However, many problems of considerable importance still await a satisfactory solution. It is clear that techniques of integrated biomanipulation show good prospects for managing eutrophic aquatic environments with a view to the ultimate recovery of their quality. The literature on food web manipulation indicates that important factor is the manipulated fish population stability (influences of anthropogenic factor or natural event like fish mortality, etc.). In case of significant change follows fish quantity the new structure might be stable for a short time (Biological Controls 2006). Complete removal of the planktivorous fish will not per se lead to optimal conditions for daphnids and stabilize. On the other hand, if the biomass of planktivorous fish exceeds a certain critical level the larger crustacean herbivores will not be able to dominate. Neither phytoplankton densities nor biomass quantities can be regulated (Gulati 1995). The new approach requires an understanding of the dynamics of water and biogeochemical processes with special emphasis on the role of biota in the catchment and aquatic systems as being a very vulnerable, but easily manageable component of the water ecosystem. The daily feed supply for aquaculture raises nutrient levels, but does not simply increase normal predator–prey activity; rather, HABs events develop often with serious ecological and aesthetic implications. The studies dealing with top-down control in the food web have not provided any tailor-made solutions for a reduction of algal bloom biomass and sustainable improvement in case of heat climate condition. Therefore, some typical problems of water quality management through biomanipulation became obvious (blue-green algae, long term stability) (Krasprzak 1995; Gulati 1995; Kasprzak et al. 2002). Therefore, the basic assumptions of the biomanipulation concept were found to be generally valid, although quantitatively hard to predict. So studies dealing with biomanipulation tool show that to achieve good prospects and sustainable improvement, it is needed provided any tailor-made solutions for a regulation of algal biomass in water resources (Afsar and Groves 1995; Krasprzak 1995; Gulati 1995).

Economical loses

A preliminary and highly conservative nationwide U.S. estimate of the average annual costs of HABs is approximately $50 million (estimate is primarily based on real estate. It does not consider many other areas that are impacted but difficult to quantify) (Ramsdell et al. 2005). Public health is the largest component, representing nearly $20 million annually, or about 42% of the nationwide average cost. The effect on commercial fisheries averages $18 million annually, followed by $7 million for recreation and tourism effects and $2 million for monitoring and management. HARRNESS does not consider many other areas that are impacted, but difficult to quantify. Full eutrophication and freshwater HABs are conservatively estimated to cost the U.S. economy 2.2–4.6 billion dollars annually (Hudnell 2010a).The actual dollar amount of these estimates is highly uncertain due to a lack of information about the overall effect of many HABs events and a difficulty in assigning a cost to those events that we do understand. While many expenses may be difficult to quantify, there is little doubt that the economic effects of specific HABs events can be serious at local and regional levels. Separate from the national average, massive losses from isolated, individual events underscore the severity of the problem. A PSP event in New England caused estimated losses of $12 to $20 million in Massachusetts alone, with additional losses in New Hampshire and Maine (Ramsdell et al. 2005). Continual PSP intoxication in Alaskan shellfish is one factor blamed for the lack of development of a commercial, wild shellfish industry, estimated to be worth $6 million annually. Blooms of one of the brown tide organisms, *Aureococcus anophagefferens*, devastated the bay scallop industry in Long Island, estimated to be worth $2 million annually. Outbreaks of *Pfiesteria*-like organisms in 1997 in Chesapeake Bay tributaries resulted in a collapse of seafood sales and boat charters, with losses to watermen, seafood dealers, and seafood restaurants approximating $43 million. Some examples are massive fish mortalities that result in fish accumulating on beaches, the closure of recreational fisheries, respiratory ailments experienced by beachgoers from aerosolized toxins, unsightly and noxious piles of macroalgae that accumulate and decompose on beaches, the discoloration of water, as well as mortalities of protected species and modification of their habitats. HABs occurrences affect consumer perceptions of the safety of uncontaminated shellfish, reducing the demand for shellfish in general and affecting the fishing and aquaculture industries even where there is no contamination. Working patterns can be disrupted when fishermen seek alternative occupations or sources of income and restaurants seek alternate suppliers for their seafood. Charter boat reservations and pier attendance for recreational fishermen in Florida can be reduced during HABs events because of fish kills, respiratory irritants, and misinformation about HABs. Vacations can be ruined, and some may never visit an impacted region again. The economic and societal impacts of HABs on fish and shellfish harvesters, producers, and processors are direct. There are periodic extensive marine mammal losses as toxins accumulate up the food chain. Their livelihoods are at risk when HABs threaten the fishery resource on which they depend. Large amounts of money are spent by the fisheries and marine culture industry to screen for toxins on a routine basis so as to ensure product safety. Weekly or more frequent monitoring is recommended only when there are at least 500 algae cells per millilitre (the most of sample analysis runs from $60 to $125 labs in Washington, depending upon the type of analysis and turnaround time requested. Even fewer labs are able to analyze for algal toxins. Some of them can only analyze for Microcystin. The cost of analysis usually runs from $300 to $500).

A subtle, but important impact of HABs is the effect they can have on recreation, tourism and local aesthetics by diminishing the quality of the coastal environment. Although many experts argue that the effects of HABs on recreation, tourism, and aesthetics are important and potentially large, there are few available data describing their magnitude. Estimating the full range of societal impacts of HABs is as difficult as estimating human behaviour in response to a traumatic event. Less recognized is the impact on community volunteers, stranding and salvage networks, federal and state regulators involved in recovery or management of plans, veterinarians, sea bird sanctuaries, environmental advocates, scientists, concerned citizens, biodiversity observers, database managers, and others.

HAB prevention, control and mitigation

The U.S. researchers vision for assessing the risk to human health, living resources, and the environment, and for implementing effective prevention and mitigation measures and for the coming decade includes recommendation aimed to develop effective, environmentally sound techniques to reduce/control HABs (Fristachi and Sinclair 2008; Lopez et al. 2008) and identification of methods for reversing eutrophication trend, if we are to have a sustainable supply of usable freshwater (Hudnell 2010b).

The long-term approach to avoid of algae bloom is the systematic removal of major nutrients and good watershed management to prevent their influx to raw water supplies (Biological Controls 2006; Warrington 2009; Hudnell 2010a, b). However, eutrophic lakes and reservoirs that have been impacted by years of poor watershed management and excessive nutrient loadings improve slowly after best management practices are implemented. Currently preventative measures of control against bloom development as well as its toxic forms through preventing of including fertilizers, animal wastes and other sources of nutrients in water resource do not achieve sustainable results and spread of the blue-green infection can reach catastrophic dimension (Fristachi and Sinclair 2008; Lopez et al. 2008; Hudnell 2010a, b). In 1972, analyses of first eutrophication survey by U.S. Environmental Protection Agency (EPA) indicated that 10–20% of all U.S. lakes and reservoirs were eutrophic the EPA recently reported that over 50% of all U.S. lakes and reservoirs are eutrophic or hypereutrophic (Hudnell 2010b).

Lake sediments usually are laden with phosphorus, and in deep lakes, the phosphorus can be released when the bottom becomes anaerobic during the summer. For this reason, much of the research into cyanobacterial toxin control has focused not on watershed management but rather on the effectiveness of various in-plant treatment processes for removing the toxins. By carefully monitoring and adjusting water treatment processes, user may be able to improve algae removal by sedimentation and filtration. The conventional treatment and disinfection of most public drinking water supplies are not effective in removing or deactivating cyanophyte toxins as well as boiling is not effective (WHO 1998; DOH 2005; Warrington 2009). Water that is free of cyanophytes may not be free of the toxins because killing the cyanophytes with chlorine, heat, mechanical disruption or any other process causes them to lyse and release their toxins into the water supply (Warrington 2009). Chemicals are widely used to prevent the growth of nuisance algae, and the commonest one being copper sulphate. But using copper sulphate in the source water also causes release of the toxins and the copper itself is toxic to benthic organisms. A number of other algicides are phenolic compounds, amide derivatives, quaternary ammonium compounds and quinine derivatives. Dichloron aphthoquinone is selectively toxic to blue-greens (BGA 2008). However, the hazards of using some toxic chemicals indiscriminately in the natural environment are well documented. Powdered activated carbon (PAC) is effective as a pre-treatment chemical prior to a conventional treatment plant according to a study of five surface water plants in Wisconsin averaging 96% removal (Warrington 2009). It can, however, cost expensive if a major bloom occurs. Granular activated carbon (GAC) was also effective, but experienced a shortened life when removing the toxin. Wood-based and coal-based activated carbons have been more effective at removing toxins than coconut-based activated carbon (DOH 2005). Nanofiltration and reverse osmosis are both very effective in removing the toxin, but initial expense can be also quite high. Ozonation is considered as the most cost-effective method for dealing with microcystin. But the effectiveness of ozonation varies depending upon the disinfectant dose and type of cyanotoxin (DOH 2005).

Biological method against algae bloom is in principle possible (SWCSMH 2007). Invertebrates like cladocerans, copepods, ostracods and snails are known to graze on green algae and diatoms. *Daphnia pulex* has been reported to feed on *Aphanizomenon flos-aquae* while present in the form of single filaments or small colonies but avoid large raft-like colonies. The copepod *Diaptomus* has been implicated in the grazing of *Anabaena* populations in Severson Lake, Minnesota. Microorganisms (fungi, bacteria and viruses) appear to play an important part in regulating growth of blue-greens in freshwaters. Certain chytrids (fungal pathogens) specifically infest akinetes, other heterocysts. Bacterial pathogens belonging to the group of Myxobacteriales can affect rapid lyses of a wide range of unicellular and filamentous blue-greens, though heterocysts and a kinetes remain generally unaffected. Viral pathogens belonging to the group of cyanophages exhibit some degree of host specifies. Phage AR-1 attacks *Anabaenopsis*, phages SM-1 and AS-1 are effective against the unicellular forms, *Synechococcus* and *Microcystis*, Phage C-1 lyses *Cylindropermum*, and the LPP-1 virus is effective against strains of *Lyngbya*, *Phormidium* and *Plectonema*. However, biological method is not always practical and effective.

Algae blooms are nothing new, especially in the shallower lakes (Minnesota 2009). Minnesotans offered the following for solving this problem: fixing faulty septic systems; preventing manure runoff from livestock pens; upgrading city sewer treatment plants to reduce phosphorus output; creating storm-water storage ponds where urban runoff can sit, while pollutants settle before the water is slowly released into bodies of water and introduction of a variety of farm cropland management techniques, including using grass buffer strips along drainage ditches and around open field tile intakes so that fertilizer and soil is filtered out. In 2001, a serious bloom of toxic cyanobacteria (blue-green algae) developed in Diamond Lake and two swimming beaches were closed. The Umpqua National Forest and Douglas County Department of Health and Social Services staff, working with private and government organizations, developed a plan to monitor the lake and a public communications strategy (Jones et al. 2009). Once the public was warned, incident team focused their attention on monitoring *Cyanobacteria*, in order to determine when the threat had diminished sufficiently to allow full use of the lake. Fortunately, Diamond Lake is not a public drinking water supply and monitoring is only needed to address recreational contact. When a serious bloom of toxic cyanobacteria reached some Wisconsin lakes and ponds, officials responsible for water quality recommended only the following: avoid using personnel watercraft, windsurfers, or water skis over mats of blue-green algae; don't swallow lake or river water; don't use it for drinking, cleaning food or washing camping gear, and don't boil contaminated water, as this may release toxins from blue-green algae; take shower after swimming; wash off your pet's coat to prevent the pet from ingesting pathogens or blue-green algae, while it cleans itself and help prevent contaminants from entering Wisconsin's recreational waters: dispose of litter in containers, do not feed the birds by swimming areas, avoid using excess fertilizers on yards and don't dump anything down storm drains.

For drinking water users the U.S. Department of Health (DOH) recommended the following: do not add an algicide if a visible bloom is present; adding an algicide can cause the algae cells to rupture, releasing toxins into the water; filtration does not effectively remove dissolved algal toxins, so destroying cells before filtration may result in higher concentrations of toxin in finished water as well as monitoring frequency for algae varies from once every other month to weekly, depending upon the quantity of algae present in the source water (Hardy et al. 2000; DOH 2005).

Wastewater treatment

The biological method stands out as most effective and economically efficient method for the purification of industrial wastewater by using the microbiological active slime and alga (Avagyan 2008b). However, bacteria of the active slime have low stability to high concentration of organic and mineral components, thus considering increased rate of water flow (Avagyan 2008b). This method also requires further destruction of superfluous quantity of active slime, which contains also pathogenic microorganisms. Sewage sludge has, unsurprisingly, proved a problematic substance for environmental law and policy. The issue of how best to dispose of it, or still better make some beneficial use of it, remains a matter of debate. Before 1998, sludge was mainly disposed of at sea, to agricultural land as fertilizer, incinerated or landfilled. In 1998, disposal at sea was banned, and carefully regulated agricultural use became the principal method of disposal. At same time it is known that active slime contains very pathogen microorganisms (*E. coli*, etc.) that prohibit using biologically active waste in agriculture. As landfilling is clearly becoming a less acceptable waste management solution, the co-processing of waste will become even more attractive in the future. The EU Landfill Directive has forced waste management policies across the member states of the EU to reduce the amount of waste sent for disposal in landfill. The directive requires that progressively increasing quantities of biologically active waste are diverted away from landfill. *May be the criteria of the Landfill Directive can become the main drivers for the production of fuel fraction through the use of active slime*? Biogas can be efficiently generated from the anaerobic digestion of sewage sludge. In this multistage anaerobic process, complex organic matter converts ultimately to CO_2 (35%) and methane (65%). However, there is a complex technological process that makes monitoring complicated (Bennett 2007). Traditionally, incineration is considered to be the next alternative for disposal, but this approach has encountered high levels of resistance in many countries at the planning and permitting stage.

Facing the future. What type of technological and economic approaches can be cost effective for restoration and development of water resources?

Biofuel manufacturing

The world is facing accelerating energy demand driven largely by global population increases and rapidly industrializing developing markets (Avagyan 2010c). Technological improvements to energy systems drive cause efficiency, and hence contribute to climate protection (Platt 2009). The U.S. government policy highlights the need for the biomass industry to develop new feedstocks that will be easier to grow, produce higher yields of biomass, and be efficiently processed into fuel, power and products that will help both technology developers and investors identify viable applications of biomass (including alga for third-generation biofuel) for fuels, power or products (USDA 2003; TAC and BRDDI 2007). The US Biomass Research and Development Technical Advisory Committee released its Roadmap lays out a concrete R&D strategy and recommends policy measures needed to improve biomass technologies and help create an economically viable, sustainable and environmentally desirable biobased industry (TAC and BRDDI 2007). The American Recovery and Reinvestment Act provide $ 787 billions, including $37.5 billions for energy efficiency and renewable energy (Platt 2009). The EU Renewable Energy Directive will create conditions enabling renewable energy to play a key role in reaching the GHG reduction target. In its strategy, the EC defines the role that biofuels, produced from biomass, a renewable resource, may play in the future as a source of renewable energy serving as an alternative to the fossil fuel energy sources (chiefly oil) used in the transport sector (An EU Strategy for Biofuels 2006; EEA 2008). It also proposes measures to promote the production and use of biofuels. Accordingly, the EU has committed itself to the "20–20–20" initiative: reducing greenhouse gas emissions by 20%, increasing the share of renewables in energy consumption to 20% compared to 8.5% today and improving energy efficiency by 20%. To put renewals into effect, in January 2008, the EC presented an integrated proposal for Climate Action aimed at providing a secure and predictable investment climate for EU industry, to which, after 11 months of legislative work, the European Parliament gave its backing Intelligent Energy—Europe II Program (IEE II 2009). The UK government recently launched a consultation on the grandfathering of dedicated biomass plants, which propose to grandfather minimum levels of support aimed to real CO_2 reduction in the short term and thereby help nurture a biomass supply infrastructure for the long term (Hannegan et al. 2010).

However, currently the U.S. and EU's trade and subsidy policies will be critical to biofuel production (Avagyan 2010c). Therefore, the burden of subsidy entirely lies upon on their taxpayers (Avagyan 2010c). *Thus, further reductions cost will be needed for biofuels to be able to compete effectively with gasoline and diesel without subsidy* (An EU Strategy for Biofuels 2006; EC Report 2007; WEO 2006; WOO 2008; Hannegan et al. 2010). According to the policy of key player's, production costs of conventional biofuels are, in general, higher than oil-based fuels; the strong expansion in the biofuel industry over the past few years have been critically dependent upon public sector support programs. In order to replace petroleum-based fuels and materials, biofuels would reach petroleum party, meaning that they are completive on physical properties, cost and scale. *How long will it take? What should be done in the future?* Recently, the combination of escalating costs for energy and foods combined with climate change has renewed interest in algae as a clean, carbon neutral energy source (Avagyan 2008a, b, c, 2010c). The biomanipulation of the surplus algal bloom can be global tool improve the situation of water resource management, will facilitate both a form of self-purification in aquatic ecosystems and significantly reduce the costs of water quality maintenance and risks posed by HABs to human health as well as the increase of supplying biofuel manufacturing profitably and boosting feed, biopharmaceuticals, etc., manufacturing in cost effective manner. Removing HABs intact cells will significantly reduce the possibility that toxins will be present in finished water since growing intact cells contain 70–100% of the toxins (DOH 2005). Moreover, macrophytes, blue green and green microalgae accumulate dissolved metals as well as heavy metals (Wilde and Benemann, 1993; Travieso et al. 1999, Mehta and Gaur 2005; Verma and Gupta 2005). Therefore, the use microalgae aimed to removal metals from water bodies used as a substitute of expensive cleanup technologies in water resource management. In this goal, our Centre developed project of biofuel manufacturing from phytoplankton addressed to Lake Sevan restoration and biodiversity conservation. This approach of demonstration and commercialization may be key water quality management new effective tool in cost effective manner, because it may be also used for the further biological engineering of the global lake and sea systems to restore biological mechanism that stabilizes the aquatic plant-dominant system, freshwater conservation, cleanup and restoration through reducing negative effect of algal blooms, lake internal surplus nutrient and heavy metals. It will create a more secure environment for power investors and users as well as offered manipulation tools application in biotic dynamics of freshwater ecosystems are synchronous with today's and future world request. Thus, this approach will promote ecologically friendly solution to restoration and cleanup of water reservoirs, conservation of drink water, and increasing quantity of valuable biomass for biodiesel manufacturing. EU Environmental Liability Directive (2004/35/EC) seeks to achieve the prevention and remedying of environmental damage, which presents a threat to human health, bringing with it a number of new or increased risks to companies and their director (Hilary 2009). The Directive has already been implemented in Italy (2006), Spain (2007), France (2008) and England (2009). Therefore, this directive raises the possibility of the use algal bloom biomass for useful purposes and grants a possibility for remedying environmental damage with obtaining profit and decreasing the risk of industries.

Additional source for biofuel, food and feed additives, biopharmaceuticals sustainable manufacturing must be alternative of active slime approach through the use of microalgae for the wastewater treatment (Avagyan 2008b, c). In the last years, the key task of our R & D was to find a solution for this problem, because microalgae, on the other hand, possess higher stability, which enables their use in more concentrated and toxic environments of wastewaters. Therefore, our Centre has carried out research to develop microalgae cultivation technologies in wastewaters containing amino acids (lysine, etc.), the wastewaters of Yerevan factory of chemical reagents and the chloroprene rubber factory Nairit (Avagyan 2008c). Also, investigated were the wastewaters of the enzyme and food industries. In the mean time, high levels of wastewater (crystallic lysine industrial manufacturing sorption effluent by BOD_5 of 45000 mg/l, COD of 50,000 mg/l, N of 4.3 g/l) purification from organic and mineral compounds were achieved (Fig. 1) and a sharp reduction of bacteria contents in microbiologically infected wastewater was observed (Table 2) (Avagyan et al. 1993). The formation of plant yield is closely intertwined with metabolism, as well as activity and concentration of photosystems (Avagyan 2010a, b). Therefore, our technological decisions included the increase of assimilability of wastewater components by Chlorella as well as optimisation of the microalgae photosynthetic process, which increased speed of wastewater purification and reduction of bacteria titre up to degree meeting the requirements for its transfer to the wastewater treatment plant.

The exhaust steam and effluent gas (including greenhouse emissions) may be used for heating microalgae suspension in biotechnological pools so the biomass manufacture not only be available year-around, but also more viable for further production (Avagyan 2008a, b). During microalgae aeration of effluent gases, CO_2 is turned into O_2 via photosynthesis that mitigates the CO_2 industrial emissions. Algae can adsorb up to 450 tons of CO_2 per acre when grown commercially (Weafer 2008).

Producing microalgae through the use and purification of wastewaters as well as microalgae processing biomass rest of biodiesel manufacturing must be an additional source of high quality feed additives. Microalgae *Chlorella* as a feed additive could become the best choice for solving problems associated with the use of high quality physiologically active feed additives and as antibiotics and organic acids alternatives in feed since microalgae contain natural organic acids, reducing the colonization of pathogens (Avagyan 2008d). In industrial test, combined feed with 1% of Chlorella powder (produced through cleaning of biotechnological wastewater) was used on 25,200 species of fishes (average weight—12.7 g). During the first 20 days, the daily average weight gain increased by 20% (0.97 g in tested and 0.73 g in the control group), and the mortality reduced by 48% (0.77 and 1.25%, respectively). Our strategy will allow producing microalgae through the use and purification of wastewaters which may be an additional source of profit, with no changes in tax law and subsidizing of nature protection actions.

Our strategy believes that including microalgae biomass of algal blooms and received through cleaning of wastewaters (Avagyan 2008b) in Industrial (such as wastewater cleaning and biofuel manufacturing (Avagyan 2008c) and

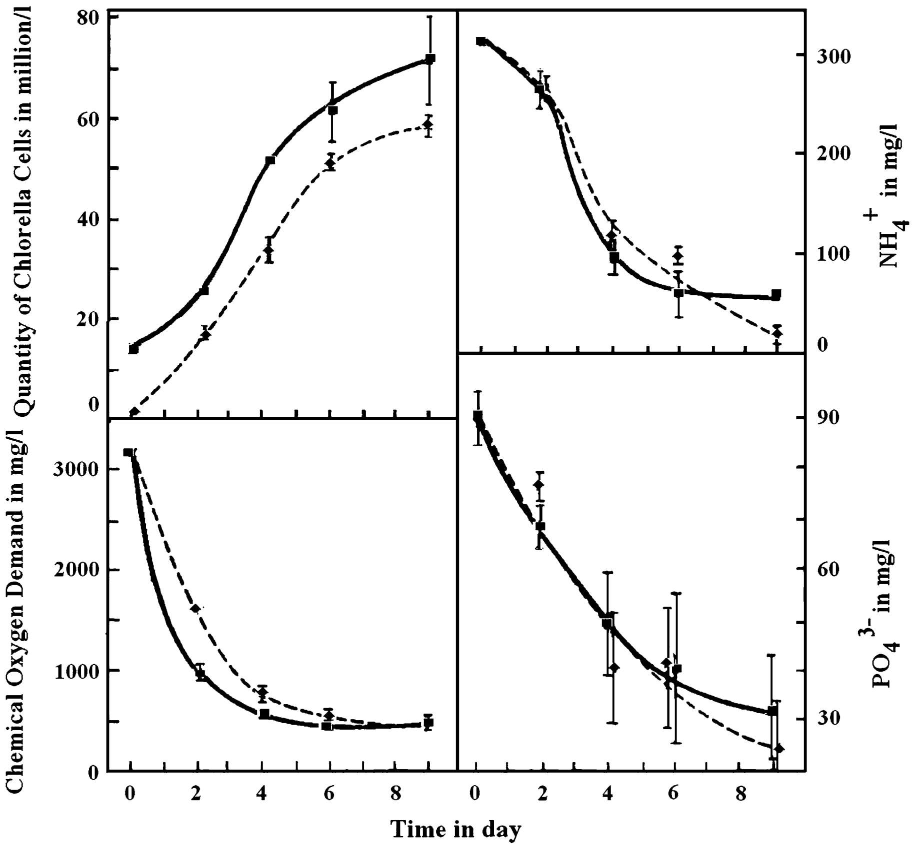

Fig. 1 Temporary variation of quantity of Chlorella cells and amount of COD, NH_4^+, PO_4^{3-} in lysine industrial wastewater in case of initial chlorella cells concentration of 14 million/ml (*square*) and 1.4 million/ml (*diamond*)

Table 2 Temporary variation of bacterial titre of lysine manufacturing wastewater, diluted by the water, during cleaning by the use of chlorella

Term in day	Quantity of bacterial cells in million per ml		
	Dilution in times		
	5	10	20
0	1,300,000 ± 60,000	650,000 ± 30,000	325,000 ± 15,000
2	34,200 ± 5,620	36,900 ± 7,330	10,480 ± 5,330
6	7,800 ± 1,860	305 ± 40	57 ± 11
9	83 ± 12	63 ± 15	22 ± 5
13	56 ± 7	22 ± 4	4 ± 1
16	7 ± 1	4 ± 1	4 ± 1

Bio (through food (Avagyan 2008b) and feed (Avagyan 2008d) additives, biopharmaceuticals (Avagyan 2010d), etc., producing from microalgae) cycles will be our adequate answer addressing to unsustainable technological improvements and climate change, thus leading to resolution of global tasks facing the world community through novel ways. Consequently, offered measures will help also reduce the greenhouse CO_2 emission, the increase in the mean time the O_2 content in atmosphere, and find optimum ways for solution of problems on how to receive raw material for biofuel and sustainable production and increase quantity and quality of end-agro-products (Avagyan 2008a, c). As a result, human life quality and health will be improved.

At the same time, my experience as reviewer show that identified approaches needed for success in the large scale algal-based projects to address the risks posed by heavy metals, radioactive isotope, green blue potent toxins as well as good knowledge in photosynthesis and other properties of microalgae.

Conclusion

At the dawn of the industrial revolution, the atmospheric concentration of CO_2 was about 280 parts per million (ppm) (UN 2008). By 2005, this figure had reached 379 ppm (IPCC 2008). The contribution of increased concentrations of CO_2 to climate change has been the subject of a broad international consensus for over twenty years. The Copenhagen climate change conference failed to find global solution to this problem. It may be difficult for existing companies to integrate principles of bioculture with the principles of their existing core business models, but that is not stopping them if new developments will be in cost effective manner. Conventional wisdom on the clash of economy and environment is that we can have it both ways, thanks to new technology and innovation. We do indeed need a revolution in technologies direct. Identifying opportunities in the next wave of technologies, along with other policy initiatives including financial crisis actions and climate policy, will affect companies' development today and in the future. World community must look at bioculture business model that will serve future sustainable development of life.

This ecological modernization can be driven by quantitative restrictions that ensure extractions from the environment do not exceed its regenerative capacities and discharges to the environment do not exceed its assimilative capacities. This analysis demonstrates the urgency required for policy and investment action in the microalgae using. Strategic heart of Global Life Conserve Industry addressed to sustainable development must be the microalgae use. Therefore, the use of bloom and wastewater cleanup algal biomass in Industrial and Bio cycles opens new ways for environmentally friendly manufacturing and water resource restoration and conservation in cost effective manner. The validity of this approach increases and confirms in the face of Biofuels Digest updated Advanced Biofuels tracking database, based on announced projects and updated company guidance tracking 56 companies with advanced biofuels projects in 13 countries (Lane 2010). According this database, third generation biodiesel volume (from algae) projected to reach 421.08 million gallons per year in 2013. The benefits of microalgae are so overwhelming that this, combined with the prospect of the improvement water resource management, makes it imperative for the world to devise an international response and a plan of action. Incentives will be needed for the development of Global Life Conserve Industry-led platforms such as the World Microalgae Technology Platform (Avagyan 2010c). It should make it possible to establish a shared World vision and strategy for the production and use of microalgae. The difficulties in realizing all this in the time frame of our analysis do not justify inaction or delay, which would raise the long-term economic, security and environmental cost.

Microalgae were the key tool for life development on earth; at present, algae produce approximately 50–70% of the atmospheric oxygen and are the World Ocean Water natural cleaner. It is an approved choice of Nature and our Centre. Therefore, microalgae must be the key tool for the water resource management addressed to new design and building sustainable development of life. *Who gains from driving forward our concept*? Offered sustainable development business model through the use microalgae and globally aggregated convenient relationship for policymakers and companies will make global goal of bioculture fully achievable.

Acknowledgments Thanks to Vice President and Director of Science of SolarBee Inc. H. Kenneth Hudnell for consultation, especially in algal bloom management.

References

Ackefors H, Hilge V, Lindén O (1990) Contaminants in fish and shellfish products. In: De Pauw N, Billard R (eds) Aquaculture Europe 89—business joins science. European Aquaculture Society Special publication no 12, pp 305–344

Afsar A, Groves S (1995) Blue-green algae management in aquaculture. Available via DIALOG. http://www.phoslock.com.au/newdocs/FRONT%20PAGE/Blue-Green%20Algae%20Management%20in%20Aquaculture.pdf

An EU Strategy for Biofuels (2006) Commission Communication, 8 February [COM(2006) 34 final, Official Journal C 67 of 18 March 2006]. Available via DIALOG. http://europa.eu/scadplus/leg/en/lvb/l28175.htm

Avagyan AB (2008a) A contribution to global sustainable development: inclusion of microalgae and their biomass in production and bio cycles. Clean Technol Environ Policy 10(4):313–317. doi:10.1007/s10098-008-0180-5

Avagyan AB (2008b) Microalgae production development global prospects and profitable technology wasterwater purification by the use microalgae. Water and Wastewater International. Available via DIALOG. http://ww.pennnet.com/articles/article_display.cfm?article_id=340236&dcmp=WaterWorldEnl

Avagyan AB (2008c) Global prospects for microalgae production for biofuels and for the preservation of nature. Global Fuel Magazine, February, pp 22–27. Available via DIALOG. http://www.propubs.com/globalfuels/eGF_Feb08_LowRes.pdf

Avagyan AB (2008d) Microalgae: big feed potential in a small package. Feed Int. 29(2):16–18. http://www.fi-digital.com/fi/200803/data/feedinternational200803-win32.zip

Avagyan AB (2010a) Correlations between delayed fluorescence of chlorophyll, metabolism and yield of plants. I. Influence of fertilizers on correlations. J Biophys Chem 1(1):40–51. doi:10.4236/jbpc.2010.11005. Available via DIALOG. http://www.scirp.org/Journal/PaperDownload.aspx?paperID=1881&fileName=JBPC20100100005_13732383.pdf

Avagyan AB (2010b) Correlations between delayed fluorescence of chlorophyll, metabolism and yield of plants. III. Influence of viral infection on field plants and new technology of clone selection of virus-free planting potato. J Biophy Chem, 1(1): 58–63. doi:10.4236/jbpc.2010.11007. Available via DIALOG. http://www.scirp.org/Journal/PaperDownload.aspx?paperID=1884&fileName=JBPC20100100007_99405055.pdf

Avagyan A (2010c) New design and build biological system addressed to global environment management and sustainable development through including microalgae and their biomass in production and bio cycles. J Environ Prot. 1(2):183–200. doi:10.4236/jep.2010.12023. Available via DIALOG. http://www.scirp.org/Journal/PaperDownload.aspx?paperID=2057&fileName=JEP20100200014_82713031.pdf

Avagyan AB (2010d) New design of biopharmaceuticals through the use of microalgae addressed to global geopolitical and economic changes. are you ready for the new development in biopharma? Pharmacol Pharmacy. 1(1):33–38. doi:10.4236/pp.2010.11005. Available via DIALOG. http://www.scirp.org/Journal/PaperDownload.aspx?FileName=PP20100100005_37241655.pdf

Avagyan AB, Arshakyan GG, Paronyan RV, Avagyan SA, Matevosyan MM, Gyulumyan EA (1993) Feasibility of purification sorption effluent from ion exchange lysine production with uses chlorella. Appl Biochem Microbiol (Russ) 29(3): 723–727

Babayan A, Hakobyan S, Jenderedjian K, Muradyan S Voskanov M (2003) Experience and lessons learned brief concerning Lake Sevan. In: World lakes. Available via DIALOG. http://www.worldlakes.org/uploads/Sevan_12.16.03.pdf

Barros P, Fidalgol ML, Soares AMVM (2001) Resistance of Cladoceran species to toxic Microcystis. Lirnnetica 20(1): 173–177. Available via DIALOG. http://www.limnetica.com/Limnetica/limne20a/Limnetica-vol20(1)-pag173-177.pdf

Bennett A (2007) Wastewater treatment and energy production. Filtration and Separation, December 16–19

BGA (2008) Blue-green alga. The guide. The Cooperative Research Centre (CRC) for water quality and treatment. Australia's National Drinking Water Research Centre. Available via DIALOG. http://www.wqra.com.au/crc_archive/dwfacts/DWF_Blue_Green_Algae_Guide_Nov08.pdf

BGADAT (2009) Blue-green algae dynamics and algal toxicity: A Study of Central Indiana Reservoirs Center for Earth and Environmental Science. Indiana University-Purdue University, Indianapolis. Available via DIALOG. http://www.cees.iupui.edu/research/water_resources/CIWRP/Algae_Information/Research.htm

Boyer GL (2008) Cyanobacterial toxins in New York and the lower great lakes ecosystems. In: Kenneth Hudnell (ed) cyanobacterial harmful algal blooms: state of the science and research needs. Springer, Berlin, pp 153–166. Available via DIALOG. http://www.epa.gov/cyano_habs_symposium/monograph/Ch07.pdf, http://www.esf.edu/communications/news/2002/08.13.toxicalgae.htm

China (2007) Premier stresses energy saving, pollution reduction. Available via DIALOG. http://news.xinhuanet.com/english/2007-07/09/content_6351121.htm

Clarke R.J (2003) Water crisis? Observer, 236. Improving water management: the OECD experience, Earthscan Publications for World Water Council, London. Available via DIALOG. http://www.oecdobserver.org/news/fullstory.php/aid/935/Water_crisis_.html

Cosgrove WJ, Rijsberman FR (2000) World water vision: making water everybody's business. Earthscan Publications, London. Available via DIALOG. http://www.worldwatercouncil.org/fileadmin/wwc/Library/WWVision/TableOfContents.pdf

Cronberg G, Annadotter H, Lawton LA (1999) The occurrence of toxic blue-green algae in Lake Ringsjön, southern Sweden. Hydrobiologia, 404(1):123–129. Available via DIALOG. http://www.springerlink.com/content/h87222812l33nj72/fulltext.pdf?page=1

DeLong JOK (2009) Toxic blue-green algae in Pewaukee Lake. Available via DIALOG. http://www.todaystmj4.com/news/local/22054514.html

DOH (2005) Water use efficiency development. Water Tap 21(3):10–12. Available via DIALOG. http://www.doh.wa.gov/ehp/dw/Water_Tap/water_tap_june_2005.pdf

EC Report (2007) Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union 2007. Commission Report of 10 January on biofuels [COM(2006) 845 final]. Available via DIALOG. http://eurlex.europa.eu/smartapi/cgi/sga_doc?smartapi!celexplus!prod!DocNumber&lg=en&type_doc=COMfinal&a_doc=2006&nu_doc=845

EEA Report (2008) Transport at a crossroads 2008. TERM 2008: indicators tracking transport and environment in the European Union. EEA report no 3/2009. Available via DIALOG. http://www.eea.europa.eu/publications/transport-at-a-crossroads

EEA Report (2009) Water resources across Europe—confronting water scarcity and drought. EEA report no 2/2009. Available via DIALOG. http://www.eea.europa.eu/publications/water-resources-across-europe

Falconer IR (1999) Cyanobacterium Cylindrospermopsis raciborskii as a probable cause of death in cattle. Environmental Toxicology, 14(1):5–12. Available via DIALOG. http://www3.interscience.wiley.com/journal/30002566/abstract?CRETRY=1&SRETRY=0

FAO (1998) Fisheries report no. 580. Rome, FAO, 56 pp. Available via DIALOG. http://www.fao.org/docrep/006/x0304e/x0304e00.htm

Frank VG, Mergen P, Philippart JC (1998) Relations between the users of water in Bütgenbach and Robertville reservoirs (Belgium). In: Symposium on water for sustainable inland fisheries and aquaculture. European Inland Fisheries Advisory Commission, twentieth session. Abstract EIFAC/XX/98/Symp. P 0.7, Praia do Carvoeiro, Portugal. Available via DIALOG. http://www.fao.org/docrep/006/X0304e/X0304e00.htm

Fristachi A, Sinclair JL (2008) Occurrence of cyanobacterial harmful algal blooms: workgroup report. In: Kenneth Hudnell H (ed) Cyanobacterial harmful algal blooms: state of the science and research needs. Springer, Berlin, pp 45–104. Available via DIALOG. http://www.epa.gov/cyano_habs_symposium/monograph/Ch03.pdf

Griffin (2009) Lake Burley Griffin open. Australian government. National capital authority. Available via DIALOG. http://www.nationalcapital.gov.au/index.php?option=com_content&view=article&catid=79:2009-media-releases&id=1030:lake-burley-griffin-open&Itemid=365

Gross JL, Pfiester LA (1988) Blue-green algae of Lake Thunderbird. Proc. Okla. Acad. Sci. 68:39–44. Available via DIALOG. http://digital.library.okstate.edu/OAS/oas_pdf/v68/p39_44.pdf

Gulati RD (1995) Manipulation of fish population for lake recovery from eutrophication in the temperate region. In: De Bernardi R, Giusanni G (eds) Guidelines of lake management. V 7. Biomanipulation in lakes and reservoirs management. UN Environment Program, Kenya, pp 53–80. Available via DIALOG. http://www.ilec.or.jp/eg/pubs/guideline/Vol.7_Biomanipulation.pdf

Hannegan E, Thompson D, Vaconute E, Parr D (2010) The big question: could bioenergy power the world. Renew Energy World 13(3):23–24

Hardy FJ, Crayton M, Jacoby J (2000) Toxic blu-green alga. DOH Pub 333-006 6/2000. Available via DIALOG. http://www.doh.wa.gov/ehp/oehas/publications_pdf/algae.pdf

Henry T (2009) New algae threat clogs shore. Freeze doesn't stop toxic growth along Lake Erie. Available via DIALOG. http://www.epa.state.oh.us/dsw/inland_lakes/Lyngbya%20wollei.pdf

Hilary B (2009) U.K. companies to face more risks under environmental directive. Business Insurance Europe, January 2

Hovhanissian R, Gabrielyan B (1998) Ecological problems related with use and management of biological resources of Lake Sevan. In: Zalewski M, McClain M (eds) Ecohydrology. UNESCO IHP-V project 2.3/2.4, Paris, p 40. Available via DIALOG. http://unesdoc.unesco.org/images/0011/001146/114659Eo.pdf

Hudnell HK (2010a) The state of U.S. freshwater harmful algal blooms assessments, policy and legislation. Toxicon 55: 1024–1034

Hudnell HK (2010b) Within water-body management: a needed but neglected complement to watershed management. Clean Technol Environ Policy 12:205–207. doi:10.1007/s10098-010-0304-6

Hudnell HK, Dortch Q, Zenick H (2008) An overview of the interagency. In: Kenneth Hudnell H (ed) International symposium on cyanobacterial harmful algal blooms (ISOC-HAB): advancing the scientific understanding of freshwater harmful algal blooms. In: cyanobacterial harmful algal blooms: state of the science and research needs. Springer, Berlin, pp 1–16. Available via DIALOG. http://www.epa.gov/cyano_habs_symposium/monograph/Ch03.pdf

IEE II (2009) Intelligent Energy Europe II Program. Available via DIALOG. http://ec.europa.eu/energy/intelligent/call_for_proposals/doc/wp2009_en.pdf

IPCC (2008) Summary for policymakers. In: Solomon S et al (eds) Climate change 2007: the physical science basis. Contribution of

Working Group I to the fourth assessment report of the intergovernmental panel on climate change, vol 2. Cambridge University Press, Cambridge. Available via DIALOG. www.ipcc.ch/pdf/assessmentreport/ar4/wg1/ar4-wg1-spm.pdf. Accessed 15 Oct 2008

Ivanyan M (2003) The influence of wastewater to the main rivers of Sevan basin. In: International workshop wastewater hygienization in constructed wetlands ponds and related system. 6–7 November, Leipzig, p 37, Available via DIALOG. http://www.ufz.de/data/Abstract_hyg6726.pdf

Jones M, Eilers, Kann J (2009) Water quality effects of blue-green algal blooms in Diamond Lake, Oregon. Available via DIALOG. http://www.stream.fs.fed.us/afsc/pdfs/Jones.pdf

Kann J, Falter CM (1985) Blue-green algae toxicity in Black Lace, Kootenal County, Idano. Research technical report of Department of Fish and Wildlife. Available via DIALOG. http://boise.uidaho.edu/default.aspx?pid=107756

Kasprzak P, Benndorf J, Mehner T, Koschel R (2002) Biomanipulation of lake ecosystems: an introduction. Freshwater Biol 47 (12):2277–2281. doi:10.1046/j.1365-2427.2002.01001.x

Krasprzak P (1995) Objectives of biomanipulation. In: De Bernardi R, Giusanni G (eds) Guidelines of lake management. V7. Biomanipulation in lakes and reservoirs management. UN Environment Program, Kenya pp 15–32. Available via DIALOG. http://www.ilec.or.jp/eg/pubs/guideline/Vol.7_Biomanipulation.pdf

Lane J (2010) Advanced biofuels tracking database. Biofuels Digest. Available via DIALOG. http://www.biofuelsdigest.com/bdigest/2010/03/23/advanced-biofuels-tracking-database/

Lopez CB, Dortch Q, Jewett EB, Garrison D (2008) Scientific assessment of marine harmful algal blooms. Interagency Working Group on Harmful Algal Blooms, Hypoxia, and Human Health of the Joint Subcommittee on Ocean Science and Technology, Washington Available via DIALOG. http://ocean.ceq.gov/about/docs/jsost_marine_habs_1208.pdf

Mehta, SK, Gaur JP (2005) Use of algae for removing heavy metal ions from wastewater: progress and prospects. Crit Rev Biotechnol. Available via DIALOG. http://www.encyclopedia.com/doc/1P3-914835101.html

Miami (2009) Cyanobacteria or blue-green algae, University of Miami NIEHS MFBS Center, Miami. Available via DIALOG. http://www.rsmas.miami.edu/groups/niehs/science/bluegreen.htm

Minnesota (2009) Our view—algae problem shows conservation need. Available via DIALOG. http://www.mankatofreepress.com/editorials/local_story_184013656.html?keyword=topstory

Pachauri R (2009) Where's the world's plan of action against climate change? Available via DIALOG. http://www.guardian.co.uk/commentisfree/cif-green/2009/jun/23/climate-change-ipcc

Pitos S, Jacson BA, Path FRC, Wood BJB (2001) Sources of the eutrophication problems associated with toxic algae: an overview. J Environ Health 64:25–32. Available via DIALOG. http://www.co.whatcom.wa.us/health/pdf/water/blue-green-algae-research.pdf

Platt G (2009) A bridge to recovery. Polimakes are pouring money into infrastructure projects in attempt to head off economic disaster. Global Finance 23(3):26–29. Available via DIALOG. http://www.gfmag.com/archives/33-march-2009/706-features-a-bridge-to-recovery.html

Ramsdell JS, Anderson DM, Gilbert PM (2005) Harmful algal research and response: a national environmental science strategy 2005–2015 (HARRNESS). Ecological Society of America, Washington, 96 pp. Available via DIALOG. http://www.whoi.edu/cms/files/HARRNESS_18189_23044.pdf

Sargsyan V (2007) Environmental security in harbors and coastal areas. Springer, Netherlands, pp 439–449. Available via DIALOG. http://www.springerlink.com/content/26768010201h1532/

Soil and Water Conservation Society of Metro Halifax (ed) (2006) Biological controls. Available via DIALOG. http://www.chebucto.ns.ca/ccn/info/Science/SWCS/biomanip.html

SWCSMH (2007) The blue-green algae (Cyanobacteria). Soil & Water Conservation Society of Metro Halifax, Dartmouth. Available via DIALOG. http://www.chebucto.ns.ca/ccn/info/Science/SWCS/cyano.html

TAC and BRDDI (2007) Roadmap for bioenergy and biobased products in the United States. Biomass Research and Development Technical Advisory Committee, Biomass Research and Development Initiative. Available via DIALOG. http://www.biomass.govtools.us

Travieso L, Cañizares RO, Borja R, Benítez F, Domínguez AR, Dupeyrony R, Valiente V (1999) Heavy metal removal by microalgae. Bull Environ Contam Toxicol 62(2):144–151. Available via DIALOG. http://www.springerlink.com/content/lcyk5k938ml6cgjt/

UN (2008) United Nations Framework convention on climate change (UNFCCC). Report of the conference of the parties on its thirteenth session, Bali, 3 to 15 December 2007, Addendum, Decision 1/CP/13, p 3. Available via DIALOG. nfccc.int/meetings/cop_13/items/4049.php. Accessed 21 Oct 2008

USDA (2003) USDA targeted incentives for greenhouse gas sequestration. Available via DIALOG. http://www.usda.gov/news/releases/2003/06/fs-0194.html

Veldhuizen DV (2009) Toxic blue-green algae. Available via DIALOG. http://www.oawu.net/H2O/2006/Winter06/Toxic.Algae.Don.pdf

Verma VK, Gupta RK (2005) Biosorption of Pb and Zn from pulp and paper industry effluent by water hyacinth (*Echhornia craissipes*). J Sci Ind Res 64(10):778–781

Walker SR, Lund JC, Schumacher DG, Brakhage PA, McManus BC, Miller JD, Augustine MM, Carney JJ, Holland RS, Hoagland KD, Holz JC, Barrow TM, Rundquist DC, Gitelson AA (2008). Nebraska experience. In: Kenneth Hudnell H (ed) Cyanobacterial harmful algal blooms: state of the science and research needs. Springer, Berlin, 139–152. Available via DIALOG. http://www.epa.gov/cyano_habs_symposium/monograph/Ch06.pdf, http://www.hhs.state.ne.us/puh/epi/CyanobacteriaFactSheet.pdf

Warrington P (2009) Aquatic pathogens cyanophytes. The blue-green algae. Available via DIALOG. http://www.env.gov.bc.ca/wat/wq/reference/cyanophytes.html

WBGA (2009) Wild blue green algae. PH Pure Health. Available via DIALOG. http://www.phpure.com/nutrition_products/pdfs/BlueGreen_Premier.pdf

WDR (2008) World development report. Adaptation to and mitigation of climate change in agriculture. Available via DIALOG. http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1192112387976/WDR08_15_Focus_F.pdf

Weafer L (2008) Food versus fuel debate continues to churn. Feed Int 29(3):6

WEO (2006) World energy outlook. International Energy Agency, Paris. Available via DIALOG. http://www.iea.org/textbase/nppdf/free/2006/weo2006.pdf

WHO 1998. Guidelines for drinking water quality, health criteria and other supporting information, 2nd edn, Addendum to vol 2. World Health Organization, Geneva

Wilde EW, Benemann JR (1993) Bioremoval of heavy metals by the use of microalgae. Biotechnol Adv 11(4):781–812. http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6T4X-476MPFT-3&_user=10&_coverDate=12%2F31%2F1993&_rdoc=1&_fmt=high&_orig=search&_sort=d&_docanchor=&view=c&_searchStrId=1387356205&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=2af79a2966357f919ad88e504e56cb91

Wilkinson I, Gulankyan S (2010) A vulnerable resourse under threat: water resource. BGS, pp 32–33. http://www.bgs.ac.uk/downloads/start.cfm?id=246

WOO (2008) World oil outlook. OPEC. Available via DIALOG. http://www.opec.org/library/World%20Oil%20Outlook/pdf/WOO2008.pdf

Xue-jun L, Ping X (1997) Seston and dissolved organic carbon dynamics during microcystis bloom with special reference to the effects of three Chinese domestic fishes in experimental enclosures. Chin J Oceanol Limnol 15(3):216–223. Available via DIALOG. http://www.springerlink.com/content/rt6015rv66707582/fulltext.pdf

Zalewski M., McClain M (eds) (1998) Ecohydrology. IHP-V project 2.3/2.4. UNESCO, Paris. Available via DIALOG. http://unesdoc.unesco.org/images/0011/001146/114659Eo.pdf