Agricultural Research & Technology
Open Access Journal
ISSN: 2471-6774

Opinion
Volume 22 Issue 2 - August 2019
DOI: 10.19080/ARTOAJ.2019.22.556194

Agri Res & Tech: Open Access J

Analyzing the Potential of Algae Farming to Provide Food, Feed and Energy from Renewable Sources

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Submission: August 12, 2019; **Published:** August 13, 2019

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Abstract

Increasingly uncertain food, water, fuel and climate security are emerging threats to economic, social and political security. Algae based biotechnologies have the potential to play an important role in mitigating these threats. For example, access to clean and at the same time affordable energy from renewable sources is an important goal to meet the United Nations' commitments on climate change. Progress to reach this goal, however, is not only about speed but mainly about direction, especially if scale-up and investment decisions are concerned. In this short note we present a tool (TELCA: Techno Economical and Life Cycle Analyses) to connect the urgent need for action with clear directions based on model guided design. The TELCA tool can be used to investigate suggested processes followed by a stepwise optimization of the critical criteria, i.e. economics, technical feasibility, energy invested on energy return, and the environmental impact in form of emitted greenhouse gas equivalents. TELCA has the capacity to analyze complex process alternatives for optimization, which is critical for processes that are new and untried but are also complex due to the biological component. Utilizing TELCA in the preparation of planning industry-scale algae-based production plants greatly de-risks scale-up and investment decisions.

Challenges in Agriculture

Agriculture and the broader bioeconomy are critical to supporting our rapidly expanding global population through the production of food, feed, renewable fuels and a wide range of bio-products. This production base however is under significant pressure from the effects of climate change which range from droughts and storms of increasing intensity, rapidly declining soil health and erosion, to Green-House Gas emissions pressures related to the production and distribution of fertilizers and agricultural goods. Emerging algae-based production technologies could offer significant support to the agricultural sector to meet these challenges.

Many of our current agricultural production systems are still largely linear, requiring the input of nutrients and freshwater to produce food, but also waste streams. To address the 'planetary boundary' constraints of fresh water, arable land, finite nutrients (e.g. phosphate), and waste limitations – 'closed-loop production models' and circular bio-economy systems are rapidly increasing in importance to expand sustainable primary production, ensure food security, enable greater GDP and export potential as well as broad range of UN Sustainability Goals [1]. Such circular processes offer improved economic, social and environmental outcomes and provide new opportunities to create jobs, enable sustainable regional development and next-generation export industries.

As microalgae are photosynthetic, highly efficient in terms of biomass production (e.g. 20g biomass dry weight m-2 = ~73t dry weight/ha/year [2] and capable of growing in saline as well as waste water, they can be used to expand photosynthetic capacity, close loops and help the industry to move from linear to more circular business models. Important opportunities include minimized waste, recycled nutrients, reduced run-off induced eutrophication and energy-intensive chemical fertilizer inputs. In summary, algae-based technologies offer a wide range of promising new product opportunities that can be integrated with existing agricultural practices to support a transition to a cleaner, greener and resilient renewable future.

Algae Based Bio-Technology and Algae Farming

Over the last 3 billion years oxygenic photosynthetic organisms including cyanobacteria, single cell green algae (microalgae), macroalgae (e.g. seaweeds) and higher plants have evolved to tap into the huge energy resource of the sun (i.e. 3020 ZJ yr-1 vs. ~0.55 ZJ yr-1 total annual global energy demand [2] and to use it to capture CO2 and nutrients and convert them into a complex set of biomolecules (e.g. proteins, lipids and carbohydrates) that collectively form biomass. This photosynthetic process is responsible for almost all carbon fixation and oxygen evolution on Earth and provides most of the energy driving the biosphere and ultimately also the human economy (e.g. fossil fuels). While agriculture has expanded crop production rapidly to meet global demand for food, feed, fuel and a wide range of products, microalgae and macroalgae production systems are technologically far less advanced despite the fact that they provide important scalable solutions to the above-mentioned challenges. These solutions include the production of a wide range of products such as [3]:

a. human nutrition (e.g. whole foods, proteins, carbohydrates, oils, anti-oxidants and poly-unsaturated fatty acids)

b. aquaculture and livestock feeds

c. renewable fuels (e.g. crude bio-oil, diesel, jet fuel, ethanol, methane and hydrogen)

d. biopolymers and nanomaterials

e. water purification

f. fine bio-chemicals

g. bio-fertilizers

h. recombinant proteins

i. bio-actives (e.g. antibiotics, antiparasitics, ecologically sensitive herbicides)

As attractive as these opportunities sound, currently algae systems are predominantly used for the production of high value products (e.g. functional foods and recombinant proteins) and significant advances must be made to drive down costs to enable cost effective commodity production such as renewable fuels for $1/L. For any emerging technology it is important to optimize systems, identify the best pathways to de-risk scale up and to establish solid business models for commercial development. In addition to optimizing the economics of the system it is increasingly important to ensure that they also deliver beneficial social and environmental outcomes. Typically, large scale production systems (e.g. 500ha) are analyzed using both techno-economic analysis (e.g. to evaluate the price of the product) and, separately, life-cycle analysis which allows social and environmental metrics to be analyzed (e.g. energy efficiency and greenhouse gas emissions). We developed a new integrated Techno-Economic and Life-Cycle Analysis model (TELCA) which optimizes systems design in terms of economic, social and environmental metrics simultaneously [4]. This has the benefit that it can fast-track the evaluation of both linear processes (e.g. CO2, water and nutrients to fuel production) and design of circular processes that maximize profitability, minimize waste and deliver improved sustainability. Such circular business models can also incorporate coproduction scenarios such as the production of food and fuel thereby improving the triple bottom-line system.

Techno-Economic and Life-Cycle Analysis (TELCA)

The scale of the challenge of climate change and the short time period remaining for transition in order to maintain food, water and energy security as well as agricultural health, means that a very rapid and yet efficient transition is required [5]. TELCA models the complete value chain from algae production, harvesting and downstream processing of the desired products, including internal recycling streams (e.g. of water and nutrients). By considering all parts of the production process simultaneously, TELCA is able to fast track complex systems optimization including the integration of biological, engineering and policy components during the plant planning process, de-risk scale-up and establish solid business opportunities. By developing this analytical tool, we have drawn on a broad range of information, including biochemistry, engineering, policy and geography. The result is a model with over 350 process, design and economic input variables and their interactions, including local, or seasonal factors such as temperature, solar irradiation, labor costs. It also takes into account geographic location as well as local policy environment. Each one can be examined and optimized to achieve peak Internal Rate of Return (IRR), Energy Return on Energy Invested (ERoEI) and Greenhouse Gas emission (GHGs), for industry scale plants operating under a wide range of conditions [4]. Analysis and optimization of systems including substantial biological inputs is an order of magnitude more difficult than assessment of conventional chemical processes. The evaluation landscape is more complex involving multiple interactive components and so requires multidimensional tools to assist in identifying optimal outputs. TELCA addresses this by incorporating the entire array of functional processes together with related cost (financial, energy and GHG) analysis into the one package. Conventional tools such as Monte Carlo analysis can then be applied to determine optimal outputs across the entire field of variables [4].

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How to cite this article: Ute C Marx, John Roles, Ben Hankamer. Analyzing the Potential of Algae Farming to Provide Food, Feed and Energy from Renewable Sources. Agri Res& Tech: Open Access J. 2019; 22(2): 556194. DOI: 10.19080/ARTOAJ.2019.22.556194