# A COMPARATIVE ANALYSIS OF CONVENTIONAL AND MICROALGAE BIOFUELS PRODUCTION

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Відеодоповідь

**Abstract**

*In recent years the intensive use of petroleum fuels has caused a major environmental impact, which prompted the search for alternative energy sources, like biofuels from crops and microalgae.*

*This study compares the microalgae and crops in terms of annual productivity of biofuels and land usage. It was concluded biofuel production using microalgae requires on average 100-fold less area than crops.*

**Keywords:** *biofuel, bioethanol, butanol, microalgae, comparative analysis, productivity*

**Introductions.** Ever-growing energy demand forces humanity to constantly depend on petroleum fuels – the major energy source, which elevates ecological concerns, due to depletion of non-renewable natural resources and the uncontrollable greenhouse gasses emission. This has motivated many researchers to explore alternative energy sources, like biofuels.

Traditional biofuels produced from agricultural crops and agricultural waste is a common alternative to petroleum fuels. However, this technology requires the use of food-grade crops and valuable natural resources for low value fuel production, which questions the rationality of using this technology [2].

Conversely, obtaining biofuels using microalgae is considered a better solution, than conventional biofuels. In comparison to crops, their advantages include much faster growth rate, higher product yields, and the capability to transform wastewater and other industrial byproducts into valuable resources. These advantages inspire numerous researchers to put this technology forward [1, 2, 4].

Despite the above-mentioned advances in the use of microalgae, there is little to no information about their success in industrial biofuel production [6]. High costs, difficulties in transitioning from experiments to industrial systems, and significant capital needs are the main barriers [6]. However, many papers explored the productivity of the microalgae on the laboratory scale, which gives an opportunity to extrapolate these findings to estimate their industrial production levels [1, 3, 5, 7].

The objective of this study is to compare the production of microalgae biofuels and conventional crop-based biofuels in terms of annual productivity, and land usage for different biofuel sources.

**Materials and methods.** The analysis was conducted by comparing the productivity of different biofuels by different plant crops and microalgae.

The annual productivity and area usage was measured in mega gallons per year (MMgal year$^{-1}$), and hectares per mega gallons per year (ha MMgal$^{-1}$year$^{-1}$) respectively. In this study the data was collected from multiple sources and later unified into the same units [1, 3, 5, 7, 9].

All data processing and visualization was carried out using R programming language and tidyverse R packages collection [10].

The reports of single country on crop-based biofuels producers were taken from the Economic Research Service of the U.S. Department of Agriculture (USDA). The information about producers in the U.S. was registered in January 2023 [9].

The discussed biofuel types were commonly used bioethanol, biodiesel, and isobutanol. The sources of crop-based biofuels were corn and soybean oil, data registered by USDA in 2023 and 2022 years respectively [9]. The microalgae biofuels were chosen to be genetically engineered cyanobacterial strains of *Synechocystis sp. PCC 6803* (*Syn6803*) and *Synechococcus elongatus PCC 7942* (*Syn7942*). The sources were selected based on their superior productivity in context of mentioned biofuel types [1, 3, 5, 7, 9].

For microalgae productivity, the research levels in micrograms per liter per hour (μg $l^{-1}h^{-1}$) was converted into the industrial levels of mega gallons per year per hectare (MMgal $year^{-1}ha^{-1}$). This assumes a volume with area of 1 hectare and depth of 1 meter was used for volumetric-to-areal conversion and the microalgae facility operated 8 hours every 292 days or 80% of full year, allocating rest of the year for facility cleaning and maintenance. The resulting factor was calculated to be approximately $6{,}172 \cdot 10^{-3}$. All other units presumed USDA standard conversions.

**Results and discussion.** From the conducted analysis it was found that microalgae have a high potential to replace crops as a source for biofuel production, while noticeably reducing land usage and saving valuable resources.

This can be seen from the graph (see Fig. 1), which shows productivity of average US crop-based biofuels producers [9] alongside the extrapolated data for microalgae for different land areas.

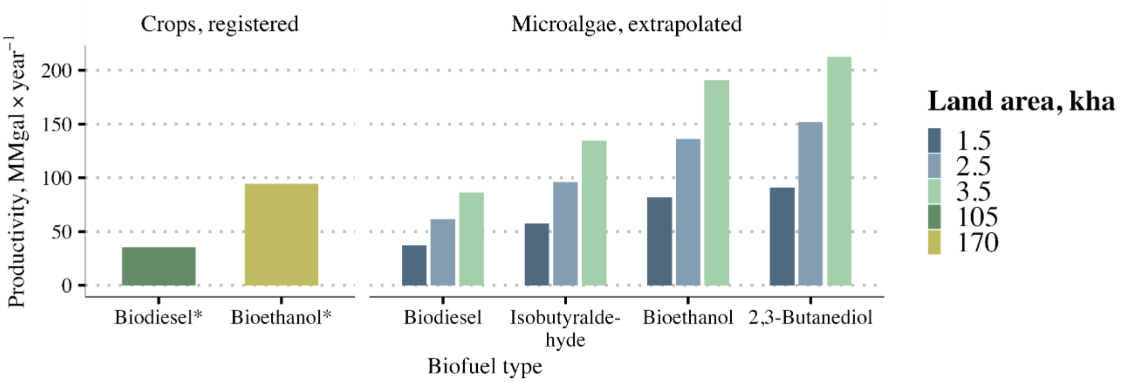

**Fig. 1. Productivity by biofuel types, colored by land area in kilohectares (kha).**
*** – refers to registered data from USDA in 2022/2023 years.**

Upon inspecting the resulted graph an interesting pattern emerges: biofuels that were produced by microalgae, especially which were genetically modified, i.e. bioethanol, isobutanol precursors – isobutyraldehyde and 2,3-butanediol, with land area of 2.5 kha showed theoretical production rate higher than that of conventional biofuels.

By comparing registered and extrapolated data it becomes clear that estimated microalgae biofuel production, except for microalgae biodiesel, given an area of 3.5 kha, can easily outperform the average conventional biofuels producer in the US.

Besides, it is also important to understand the efficiency of individual biofuels sources in terms of the required area to produce 1 mega gallon per year. The resulting graph (see Fig. 2) clearly shows that all microalgae biofuels require at least 100-fold less land area than conventional biofuel sources, with minimum required area for isobutanol biofuels produced by *Syn7942*.

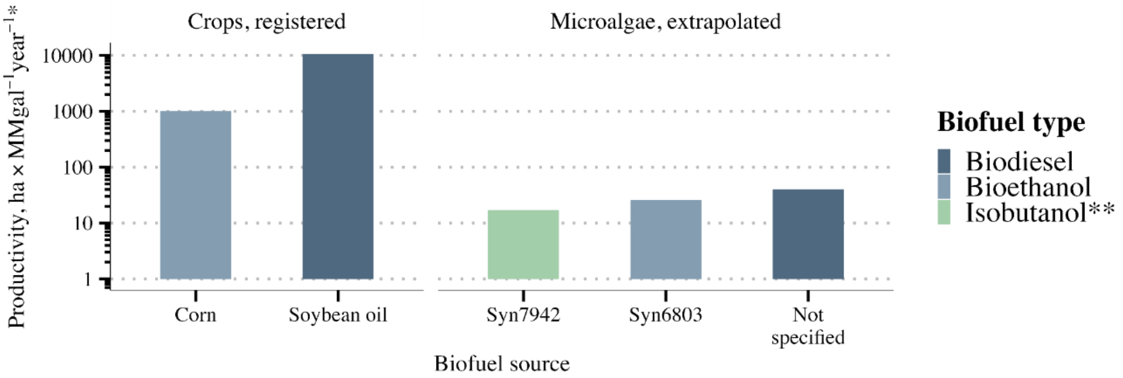

**Fig. 2. Productivity by fuel source, colored by fuel type; * – Axis was scaled by log10 for readability; ** – refers to isobutyraldehyde and 2,3-butanediol as precursors of isobutanol.**

Additionally, it is essential to highlight another drawback of crop-based biofuels, as depicted in the graph below (see Fig. 3). It illustrates the usage of corn and soybean oil from 2001 to 2022, with a rapid climb of biofuel share up to 40-50%. This shift from food to fuel production contributes to significant food shortages and land exhaustion. To overcome these issues, alternative sources, like microalgae can be adopted to maintain ecological balance and ensure sustainable resource use.

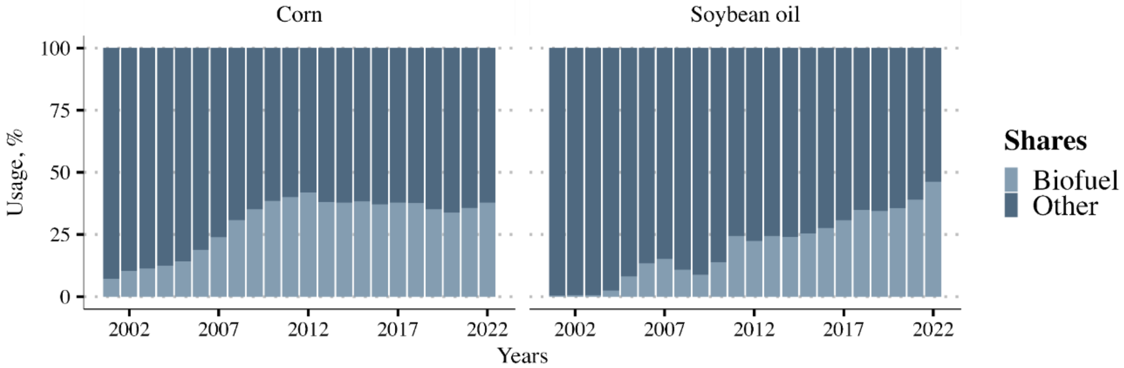

**Fig. 3. Usage of corn and soybean oil in 2001–2022 years, colored by shares of use.**

Apart from microalgae exceptional theoretical productivity, the overall microalgae biofuels technology realization is debatable, due to high equipment and material costs including the additional efforts of integrating biofuels into current fuel infrastructure. Moreover, the final price of the biofuels must be assessed as it plays a crucial role in the understanding of economic viability of the technology [2, 4].

Whilst actual microalgae biofuels facilities have not been achieved, some researchers have already developed simulations of microalgae biofuel production scenarios. This gives the ability to evaluate significant economic criteria, such as return on investments, operational costs and minimal fuel selling prices [6].

For instance, Branco-Vieira et al have successfully modeled a production system for cyanobacterial strain *Phaeodactylum tricornutum* whose resulting price was estimated to be 2.01 euro $kg^{-1}$ of biomass and 0.33 euro $l^{-1}$ of biodiesel respectively. Additionally, the return of investment was calculated to be 10% with 10 years payback time. Despite the project's medium viability, authors stated that this biofuel could not compete on the current fuel market, due to much lower costs of fossil fuels [6]. Nevertheless, this opens an opportunity for new-generation biofuels, such as higher alcohols (butanol, pentanol, hexanol, etc.), which have already beaten other biofuel both in energetic characteristics and productivity [1, 5, 8].

**Conclusions.** This finding concluded that for producing biofuels microalgae require approximately 100 times less land area than it would be needed by an average US crop-based biofuels producer. This opens the possibility to entirely replace crop-based biofuels with technology of higher productivity, saving numerous valuable resources and preserving the land for growing food instead of fuel.

However, to establish feasible microalgae biofuel technology further research and development are required to ensure stable fuel productivity and lower material and operational costs.

## References:

1. Atsumi S., Higashide W., Liao J. C. Direct photosynthetic recycling of carbon dioxide to isobutyraldehyde. Nature biotechnology. 2009. Vol. 27, no. 12. P. 1177–1180. URL: https://doi.org/10.1038/nbt.1586 (date of access: 08.05.2024).
2. Chisti Y. Biodiesel from microalgae beats bioethanol. Trends in biotechnology. 2008. Vol. 26, no. 3. P. 126–131. URL: https://doi.org/10.1016/j.tibtech.2007.12.002 (date of access: 08.05.2024).
3. Chisti Y. Biodiesel from microalgae. Biotechnology advances. 2007. Vol. 25, no. 3. P. 294–306. URL: https://doi.org/10.1016/j.biotechadv.2007.02.001 (date of access: 08.05.2024).
4. Current issues and developments in cyanobacteria-derived biofuel as a potential source of energy for sustainable future / K. B. Singh et al. Sustainability. 2023. Vol. 15, no. 13. P. 10439. URL: https://doi.org/10.3390/su151310439 (date of access: 08.05.2024).
5. Cyanobacterial conversion of carbon dioxide to 2,3-butanediol / J. W. K. Oliver et al. Proceedings of the national academy of sciences. 2013. Vol. 110, no. 4. P. 1249–1254. URL: https://doi.org/10.1073/pnas.1213024110 (date of access: 08.05.2024).
6. Economic analysis of microalgae biodiesel production in a small-scale facility / M. Branco-Vieira et al. Energy reports. 2020. Vol. 6. P. 325–332. URL: https://doi.org/10.1016/j.egyr.2020.11.156 (date of access: 08.05.2024).
7. Photosynthetic production of ethanol from carbon dioxide in genetically engineered cyanobacteria / Z. Gao et al. Energy Environ. Sci. 2012. Vol. 5, no. 12. P. 9857–9865. URL: https://doi.org/10.1039/c2ee22675h (date of access: 08.05.2024).
8. Tailoring the key fuel properties using different alcohols (C2 – C6) and their evaluation in gasoline engine / B. M. Masum et al. Energy conversion and management. 2014. Vol. 88. P. 382–390. URL: https://doi.org/10.1016/j.enconman.2014.08.050 (date of access: 08.05.2024).
9. USDA ERS - U.S. bioenergy statistics. USDA ERS - Home. URL: https://www.ers.usda.gov/data-products/u-s-bioenergy-statistics/ (date of access: 08.05.2024).
10. Welcome to the tidyverse / H. Wickham et al. Journal of open source software. 2019. Vol. 4, no. 43. P. 1686. URL: https://doi.org/10.21105/joss.01686 (date of access: 08.05.2024).