USE OF ALGAE FOR BIOFUEL PRODUCTION: REVIEW OF INTERNATIONAL EXPERIMENTAL STUDIES

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Abstract. *The paper presents experimental studies on algae-based biofuels in Japan, the U.S., India, Europe, and beyond. Algae show high potential for renewable fuel production due to high yield, CO_2 capture, and non-arable land use. Case studies illustrate strain, cultivation, and conversion innovations.*

Keywords: *algae biofuel, microalgae, macroalgae, jet fuel, photobioreactor*

Introduction.Microalgae and macroalgae (*Chlorella, Nannochloropsis, Laminaria, Ulva*) are considered promising biofuel feedstocks due to their high productivity, CO_2 fixation, and ability to grow on non-arable land [1, 2]. Despite significant interest during the 2010s, the sector faced major technical and economic challenges [3, 4]. Between 2018 and 2024, renewed research efforts in Japan, the USA, Europe, India, and China have revitalized progress in strain selection, cultivation systems, and biomass processing [1]. This work aims to summarize current international experimental approaches to algae-based biofuel production and to outline the key challenges to its commercialization.

Materials and methods. This study is based on a review of experimental and pilot-scale research on algae-based biofuels conducted between 2018 and 2024, covering projects from Asia, Europe, and the Americas [1]. The analysis is structured around three key stages: algae cultivation, biomass harvesting and lipid extraction, and conversion into biofuels. Both microalgae (*Chlorella, Nannochloropsis, Botryococcus*) and macroalgae (*Laminaria, Ulva*) were studied. Cultivation systems included open raceway ponds, closed photobioreactors (PBRs), and hybrid schemes.

Results and discussion. Recent innovations have focused on improving PBR design and CO_2 delivery to enhance biomass and lipid yields [1].

Figure 1 illustrates the main types of cultivation systems used in these studies:

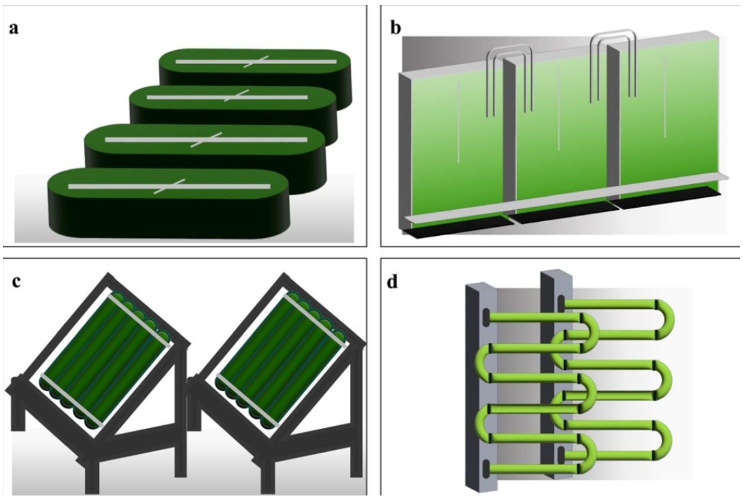

Fig. 1. Typical microalgae cultivation systems used in biofuel experiments.a)open shallow raceway ponds with paddle wheels, (b) flat-panel photobioreactors (PBRs), (c) inclined tubular PBRs, (d) multi-loop tubular PBR systems [4].

Table 1. Stages of Algal Biomass Processing.

Stage	Description	Innovations and Examples
Harvesting and Lipid Extraction	A critical but energy-intensive step. Traditional methods (e.g. centrifugation, solvent extraction) remain costly.	- SPS (Switchable Polarity Solvent) method in India allows eco-friendly lipid extraction with solvent reuse without distillation [3]. - Magnetic nanoparticles, bioflocculants – enable easier biomass separation. - Use of wastewater or CO_2 from power plants helps reduce costs.
Conversion to Biofuels	Algal biomass can be converted into various fuels depending on composition: lipids → biodiesel (transesterification), carbohydrates → ethanol (fermentation), residues → biogas, bio-crude (HTL, pyrolysis).	- MacroFuels (EU): ethanol, butanol, furanic fuels from seaweed, engine-tested [8]. - USA and Japan: HTL and hydroprocessing for jet fuel that meets fuel standards [1], [13]. - Biorefineries: co-products like fertilizers, animal feed.

The table below summarizes the outcomes of leading international studies on algae-based biofuel production conducted between 2018 and 2024. Table 2 provides a brief overview of key achievements and technologies used.

Table 2. Case Studies of Internamtional Algae Biofuel Experiments.

Country / Region	Highlights	Key Achievements
Japan	Japan developed domestic technologies for algae-based sustainable aviation fuel (SAF). The project focused on microalgae (*Botryococcus braunii*), known for its high hydrocarbon content.	- Euglena Co. built the first algal biofuel demonstration plant in Yokohama (2018) [2]. - In 2021, the companies JAL (Japan Airlines) and ANA (All Nippon Airways) operated commercial flights with 9.1% algal-derived jet fuel blends [1]. - Fuel certified under ASTM (American Society for Testing and Materials) D7566 standards, a first for Japan [1]. - Open Pond cultivation scaled in Japan and Thailand.
USA	The U.S. leads in algal biofuel research volume. A combined public-private effort focuses on integrating	- DOE (U.S. Department of Energy) invested \$20 million into algae R&D in 2020 [7]. - Viridos Inc. engineered algae strains with enhanced lipid productivity; received \$25M from United Airlines, Chevron, Breakthrough Energy (2023) [6]. - Pilot plants tested HTL (hydrothermal liquefaction) for bio-crude production [6]. - Projects aligned with the SAF

		Grand Challenge (target: 3 billion gallons by 2030).
India	India focuses on affordable biofuel production by optimizing native strains and developing low-cost processing.	- NIT-T team isolated *Picochlorum*, *Scenedesmus*, and *Chlorella* strains with >50% lipid content under stress [3,11]. - Developed the SPS solvent method, allowing solvent reuse without distillation [3]. - Magnetic nanocomposites used for harvesting microalgae. - Biodiesel produced met ASTM D6751 fuel quality standards.
Europe	Europe emphasizes macroalgae (seaweed) cultivation and integrated biorefineries producing multiple fuels and co-products.	- MacroFuels project (2016–2019): ethanol, butanol, biogas, and furanics produced from kelp [8]. - Seaweed demonstrated easier fermentation than terrestrial biomass (no lignin) [10]. - Launched FUELGAE project (2023–2027) to integrate CO_2-capturing algae bioreactors at industrial sites [9]. - Achieved wet seaweed yields of up to 25 kg/m²/year.
China	China focuses on scaling outdoor algae cultivation using waste CO_2 and desert resources.	- Pilot projects cultivating hardy algae on desert land with saline groundwater [4]. - Flue gas from power plants fed into algal ponds. - Aimed at producing 5000 tons of algal biofuel annually in demonstration plants (announced 2021). - Strategic investment for national energy security.
Canada	Canada links algae cultivation with industrial waste treatment and climate adaptation strategies.	- Algae grown in photobioreactors using flue gases from oil sands facilities (Alberta project). - Focus on cold-tolerant native algae strains. - Pond Technologies developed systems to harvest algae grown on factory emissions.
Australia & New Zealand	Both countries capitalize on native species for bio-crude and seaweed energy projects.	- Muradel HTL pilot plant (Australia). - Small-scale seaweed biofuel projects (New Zealand).
Belize (Caribbean)	Innovative approach to convert invasive seaweed into biofuels,	- $50M public-private partnership launched in 2023 to pyrolyze sargassum blooms into diesel-like

	addressing environmental and energy challenges.	fuels [12]. - Combines seaweed with municipal waste. - Potential model for other island nations.
Middle East & South Korea	New pilot efforts link algae with desalination plants and coastal industrial ecosystems.	- CO_2 and brine from power and desalination used in algae pilots. - South Korea operates a national "algae fuel test-bed" on the southern coast. - Focus on energy and water security.

Conclusion. According to the reviewed literature, algae-based biofuels have demonstrated technical viability in multiple pilot projects. While commercialization remains limited, innovations such as SPS extraction, HTL, and CO_2-integrated cultivation show promise for cost reduction. Global support and policy-driven programs are expected to foster further deployment.

References

1. Wang, M., et al. (2024). "Microalgae biofuels: illuminating the path to a sustainable future amidst challenges and opportunities." Biotechnology for Biofuels and Bioproducts,biotechnologyforbiofuels.biomedcentral.com.
2. Reuters – Briceno, J. (2023). "Belize to launch project to make biofuel from seaweed clogging Caribbean coasts." Reuters Tech News, 3 Oct 2023 reuters.com.
3. Mongabay News – Nairn, C. (2023). "As Exxon bows out, industry takes step toward sustainable algae biofuels." 9 May 2023news.mongabay.com.
4. U.S. Department of Energy (2024). "U.S. DOE Announces $20.2 Million in Projects to Advance Development of Mixed Algae for Biofuels and Bioproducts." Office of EERE Press Release, 14 Nov 2024 energy.govenergy.gov.
5. Surgenor, C. (2021). "Japan Airlines and ANA operate SAF flights with fuels made from wood chips and microalgae." GreenAir News, 22 June 2021 greenairnews.com.
6. Euglena Co. (2018). "Japan's skies with biofuel – First biojet fuel flight." Sustainable
7. Mongabay News – Nairn, C. (2023). "As Exxon bows out, industry takes step toward sustainable algae biofuels." 9 May 2023news.mongabay.com.
8. U.S. Department of Energy (2024). "U.S. DOE Announces $20.2 Million in Projects to Advance Development of Mixed Algae for Biofuels and Bioproducts." Office of EERE Press Release, 14 Nov 2024 energy.govenergy.gov.
9. Wang, M., et al. (2024). "Microalgae biofuels: illuminating the path to a sustainable future amidst challenges and opportunities." Biotechnology for Biofuels and Bioproducts,biotechnologyforbiofuels.biomedcentral.com.
10. CORDIS EU Project Report (2020). "MacroFuels – Developing the next generation macro-algae based biofuels." Final Report Summary, EU Horizon 2020 Project 654010 cordis.europa.eu.
11. FUELGAE Consortium (2024). "New EU-funded FUELGAE project aims to resurrect algae as a promising source for aviation biofuels." GreenAir News, 12 Jan 2024 greenairnews.com.
12. Banerjee, A. et al. (2022). "Biofuel production from Macroalgae: present scenario and future scope." Bioengineered, 13(2): 4923–4941 pmc.ncbi.nlm.nih.gov
13. FUELGAE Consortium (2024). "New EU-funded FUELGAE project aims to resurrect algae as a promising source for aviation biofuels." GreenAir News, 12 Jan 2024 greenairnews.com.