Biofuel Production Metrics from Marine Microalgae Species (*Chlorella* and *Nannochloropsis*)

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ABSTRACT

Global energy crises and environmental impacts from fossil fuels have prioritized microalgae as third and fourth-generation biofuel feedstocks. This study analyzes production metrics for the genera Chlorella and Nannochloropsis, focusing on lipid accumulation for biodiesel and carbohydrate yields for bioethanol. Nannochloropsis sp. exhibits high lipid contents ranging from 31% to 68% of dry weight, while Chlorella vulgaris can reach 55% under optimized nutrient limitations. Extraction techniques such as NaCl osmotic shock (120 atm) and microwave irradiation have been shown to significantly enhance oil yields and efficiency. For bioethanol, Chlorella pyrenoidosa provides a carbohydrate reservoir of 37-55%, yielding up to 28.07% bioethanol through enzymatic hydrolysis and fermentation. Physical metrics of produced biodiesel, including a density of 0.84 g/mL and an average cetane number of 52, comply with international standards. This review integrates 20 distinct studies to provide a comprehensive metric-based evaluation of marine microalgae as a sustainable energy factory.

Keyword : Biodiesel, Bioethanol, Lipid Content, Microwave Irradiation, Osmotic Shock, Biomass Productivity.

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1. INTRODUCTION

The depletion of non-renewable fossil fuel reserves and the escalating threat of climate change driven by CO2 emissions have catalyzed the search for sustainable energy alternative[1], [2], [3]. Microalgae have emerged as the most promising candidate due to their photosynthesis efficiency, which is 10 to 50 times higher than that of terrestrial plants[1], [4]. Unlike traditional bioenergy crops, microalgae do not compete with food security or require fertile agricultural land[5].

Among marine species, the genera *Chlorella* and *Nannochloropsis* are widely recognized for their rapid reproduction and high energy density[4], [6]. *Nannochloropsis oculata* is valued for its ability to grow at high cell densities and produce substantial lipid volumes, often exceeding 50% of its dry biomass[7]. Simultaneously, *Chlorella* species are versatile, showing significant potential for both biodiesel and bioethanol production, while doubling as effective agents for wastewater remediation[5].

This paper provides a detailed synthesis of production metrics, covering biomass productivity, lipid and carbohydrate profiles, and the thermal efficiency of conversion technologies. By examining specific variables such as nutrient limitation, light wavelength, and extraction methods, this review aims to establish a benchmark for the industrial-scale viability of marine microalgae-derived biofuels[8].

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2. METHOD

2.1. Microalgal Strains and Cultivation Systems

The primary species analyzed include *Nannochloropsis oculata*, *Chlorella vulgaris*, *Chlorella pyrenoidosa*, and specific marine strains such as *Chlorella sp*[7], [9]. TAD. Cultivation often employs batch systems or specialized reactors like the Rotary Algae Biofilm Reactor (RABR). Key environmental parameters monitored include[10]:

- **Salinity:** Optimized at 28-30 ppt for marine species.
- **Light Intensity:** Generally maintained at 2000 lux or 67.5 µmol m−2s−1, with studies indicating blue light (450-495 nm) maximizes lipid accumulation.
- **Nutrients:** Common media include Conway and F/2 solutions, often supplemented with urea and glucose for mixotrophic growth.

2.2. Harvesting and Biomass Preparation

Harvesting is performed via centrifugation (3000-5000 rpm), sedimentation, or filtration using plankton nets[2]. Collected biomass is typically dried through convective heating (oven-drying at 60°C) or freeze-drying (lyophilization) to preserve biochemical integrity[11].

2.3. Extraction and Conversion Protocols

1. **Lipid Extraction:** Methods include Soxhlet extraction using n-hexane, the Bligh-Dyer method (chloroform:methanol), and physical cell disruption techniques such as microwave irradiation and ultrasonic homogenization[4], [12].
2. **Osmotic Shock:** NaCl solutions are utilized to create osmotic pressure (up to 120 atm), effectively rupturing cell walls to release lipids[2].
3. **Hydrolysis for Bioethanol:** Biomass is subjected to acid hydrolysis (H2SO4) or enzymatic hydrolysis (alpha-amylase from *Aspergillus niger*) to convert complex polysaccharides into fermentable glucose[9], [13].
4. **Fermentation and Transesterification:** Glucose is fermented using *Saccharomyces cerevisiae*. Lipids are converted to Fatty Acid Methyl Esters (FAME) through base-catalyzed transesterification with methanol and KOH[5].

3. RESULT AND DISCUSSION

3.1. Biomass and Growth Metrics

Growth dynamics of *Nannochloropsis oculata* show distinct phases: adaptation (lag), exponential, and death. In small-scale laboratory cultures (1L), biomass can reach 21.6 million cells/mL. However, scaling up to 40L often results in lower cell density due to "self-shading" and light penetration efficiency. *Chlorella sp.* TAD demonstrates a productivity of 0.151 g/L/h, reaching maximum density around day 22[7].

3.2. Lipid Production and Biodiesel Metrics

Lipid content is the most critical metric for biodiesel viability. *Nannochloropsis sp.* consistently reports higher baseline lipids (31-68%) compared to *Chlorella vulgaris* (14-22%). Under "stress conditions," such as nitrogen starvation and blue light exposure, *Chlorella sp.* lipid content can be boosted to 40.91% [4], [14].

Table 1. Lipid Yield Comparison based on Extraction Method

Species	Extraction Method	Oil Yield (% dry wt)	Source
Nannochloropsis sp.	Osmotic Shock (120 atm)	3.96% (Wet) / 2.60% (Dry)	[2]
Nannochloropsis oculata	Conventional Soxhlet	37%	[2]
Chlorella sp.	Microwave Irradiation	35%	[4]
Chlorella sp.	Ultrasonic + Enzyme	14.90 - 15.96%	[5]

3.3. Bioethanol Production Metrics

Bioethanol metrics depend on the carbohydrate reservoir. *Chlorella pyrenoidosa* contains 37-55% carbohydrates[9]. Using a 40% concentration of alpha-amylase for hydrolysis, glucose levels of 0.67 mg/mL are achieved, which ferment into bioethanol with a yield of 28.07%. Conversely, *Chlorella TAD* yields a lower carbohydrate content of 3.14%, resulting in a 3.43% bioethanol concentration[15].

3.4. Fuel Quality and Standards

Biodiesel derived from *Chlorella sp.* aligns with Indonesian National Standards (SNI) and ASTM standards.

Table 2. Biodiesel Characteristic Metrics

Parameter	Chlorella sp. Biodiesel	Standard (SNI)	Unit
Density	0.84 - 0.848	0.84 - 0.89	g/mL
Viscosity	2.50 - 3.91	2.3 - 6.0	cSt
Cetane Number	51.17 - 53.72	Min 51	
Flash Point	131	Min 100	°C
HHV	44.04	37.11	MJ/Kg

Nannochloropsis bio-oil produced via pyrolysis at 300°C achieves a higher heating value (HHV) of 32 MJ/kg[12].

3.5. Thermal Conversion and Efficiency

Microwave-assisted extraction (MAE) proves 1.3 times more thermodynamically efficient than conventional heating[4]. Microwave irradiation can accelerate heating up to 100 times faster because it bypasses the traditional conduction/convection pretreatment, causing rapid cell wall rupture via localized moisture vaporization[4], [16].

3.6. Integration with Wastewater Treatment

The metrics for "Green Energy" include environmental remediation. *Chlorella sp.* cultivated in hotel liquid waste can reduce Ammonia-Nitrogen and COD by up to 70% while simultaneously accumulating lipid. Using fishery waste as a medium, bioethanol production is estimated at 20,000 L/ha, offering a dual solution for waste management and fuel production[3].

4. CONCLUSIONS

Production metrics for *Chlorella* and *Nannochloropsis* confirm their status as superior biofuel feedstocks. *Nannochloropsis sp.* excels in lipid density, with optimized osmotic shock and microwave technologies facilitating higher recovery rates for biodiesel. *Chlorella pyrenoidosa* demonstrates exceptional bioethanol potential with carbohydrate yields exceeding 50%. Physical fuel characteristics of density (0.84 g/mL) and cetane numbers (>51) consistently meet international standards, suggesting that marine microalgae can realistically substitute fossil-based diesel. The integration of cultivation with wastewater treatment enhances the economic and environmental sustainability of the process.

5. REFERENCES

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