Algae to reduce CO_2

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Problem

Excess CO_2 in Water

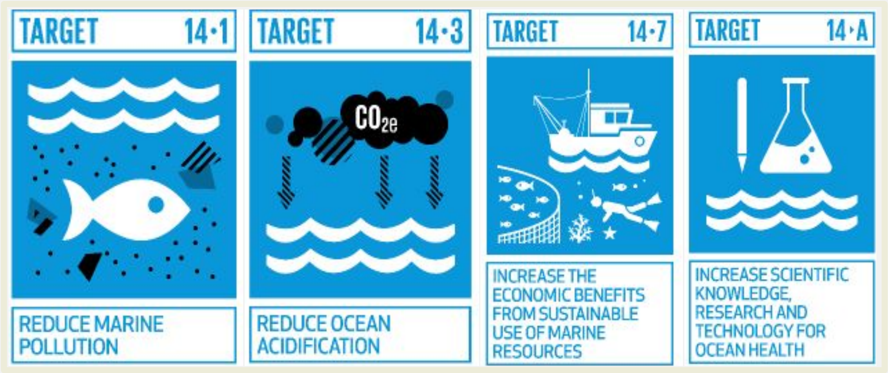
High levels of CO_2 in water contribute to **ocean acidification**, which lowers the pH of water and harms marine ecosystems.

Carbon credits. Each carbon credit represents the right to emit one tonne of greenhouse gases.

"Over 3 billion people depend on marine and coastal biodiversity for their livelihood"

Purpose

“Enhancing the efficiency of algae cultivation by selecting the most suitable species for each environment while preserving existing ecosystems and minimizing waste.”



Technologies for CO_2 Reduction

01

Value Chain

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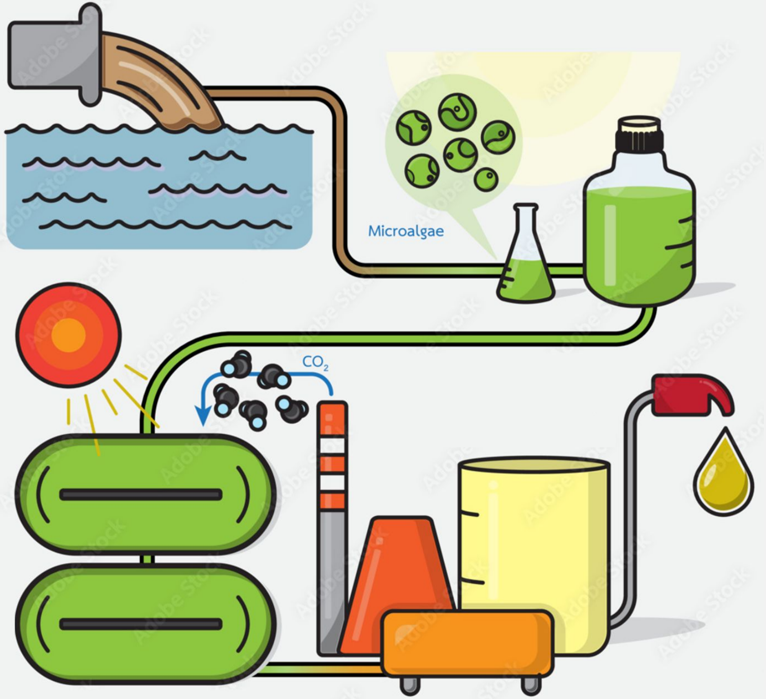
Value Chain



Microalgae Cultivation

Cultivation Systems

Harvesting & Processing

Biofuel Conversion

Check Annexes for more detail

Solution Proposals

Sensor Monitoring & Control Systems

- **Water quality** parameters
- **CO_2 concentration** and absorption metrics
- **Algae growth** and **health** indicators
- **Nutrient** composition analysis

Integrated Automation

- **Cultivation** & **Harvesting**
- **Smart systems** and **cycles**
- Real-time **monitoring** systems
- **Automated** processes

Data Integration & Analytics

- Remote **monitoring** and **management**
- Predictive **analytics** for forecasting

Process Improvements

Microalgae Cultivation

Optimum selection of algae strains based on the **environment**:

- pH levels
- Nutrient composition
- Salinity measurements
- Organic pollutants

Cultivation Systems

- Automated responses to **environmental changes**
- **Automated process** (cleaning, nutrient delivery, ...)
- **Optimization of growth** conditions
- Reduced **labour costs**

Harvesting & Processing

- Continuous harvesting for **optimal CO_2 absorption**
- **Reduces** energy consumption
- Closed-loop systems prevent **culture contamination**

Technological Analysis

01

Keywords & Sources

02

Statistical Analysis

Keywords & Sources

Bio-Circular-Green
Agricultural
(Pollution) Value
Fixation Waste bio-capture
CO2 microalgae Chain
Energy Solid Fuels
(BCG) Biofuel Sustainable
Engineering
economy

559,609

Web of Science

7,330

WIPO Patents

395

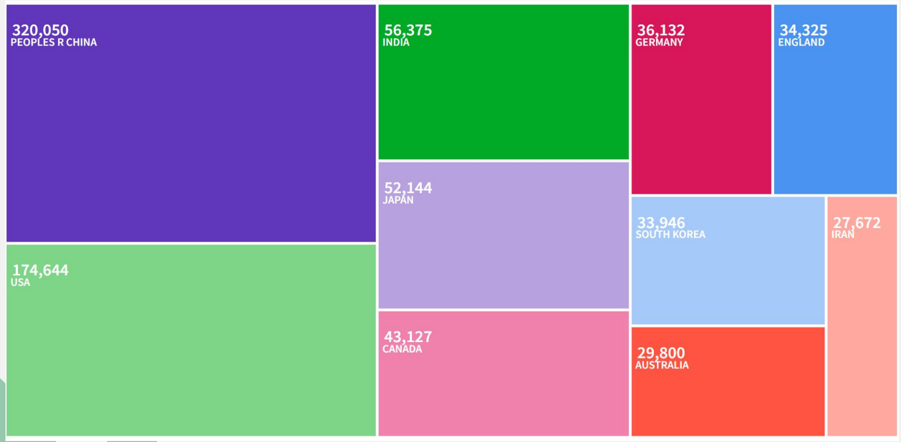
CORDIS

Statistical Analysis

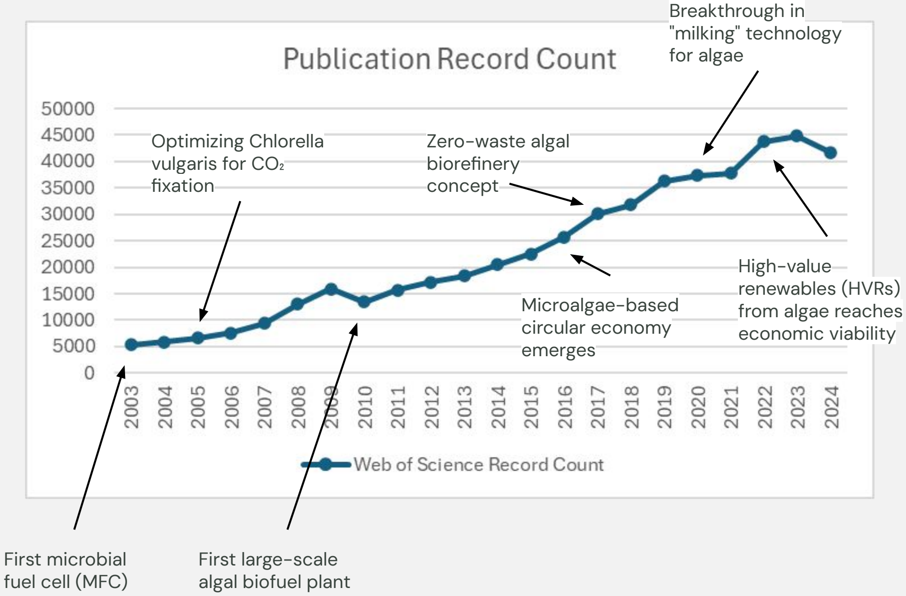
Up to **32**% better efficiency against coal firing methodologies

Up to **93**% CO2 consumption efficiency against alternative methods

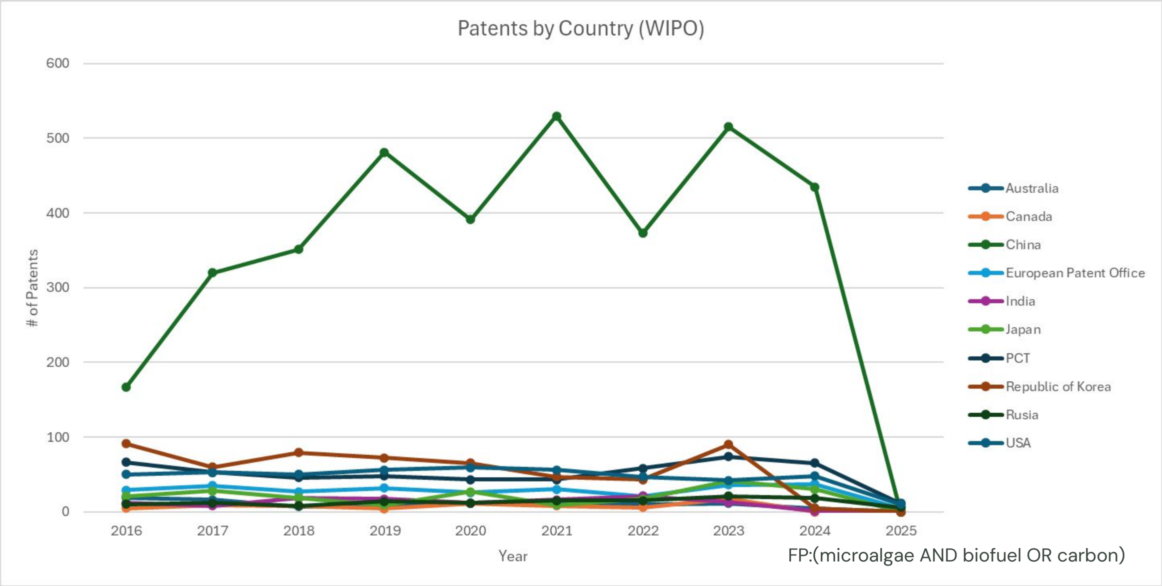
0% waste with biorefinery mechanisms that yield multiple products



Trend in technological advancements



Business Analysis



Accords

- **Paris Climate accords (2015)**: Reduce global greenhouse gas (GHG) emissions by 45

- **COP28 UAE Climate Deal (2023):** Agreement to transition away from fossil fuels

Facts

- The algae biofuel market is projected to grow from **$8.55 billion** in 2024 to **$9.37 billion** in 2025

- While **Asia-Pacific** dominates the market due to favourable climatic conditions. **North America** is leading R&D

Conclusions

Sustainable Solution

Microalgae-based biofuel production is an effective natural solution for **reducing CO_2 emissions** and combat **climate change**

Technology for CO_2 Reduction

Advanced **cultivation**, **harvesting**, and **biofuel conversion** improve efficiency and sustainability

Automation & Data Integration

Smart monitoring, **predictive analytics**, and **automated systems** optimize processes and reduce costs

Needs & Challenges

Policy support, **investment**, and **circular economy integration** are needed for a future large-scale adoption

Thank you.

References

- Goals 14: Life below water
- Carbon Credits Explained: A Beginner’s Guide to the Voluntary Carbon Market | by Bitgreen
- Life Below Water: Why it matters
- Optimization of CO_2 bio-mitigation by *Chlorella vulgaris*
- Circular zero -residue process using microalgae for efficient water decontamination, biofuel production, and carbon dioxide fixation
- Innovations in algal biorefineries for production of sustainable value chain biochemicals from the photosynthetic cell factories
- Microalgae as tools for bio-circular-green economy: Zero-waste approaches for sustainable production and biorefineries of microalgal biomass
- Unlocking the potential of microalgae as sustainable bioresources from up to downstream processing: A critical review
- Zero-waste algal biorefinery for bioenergy and biochar: A green leap towards achieving energy and environmental sustainability

References

- Design and Test of a Low-Cost RGB Sensor for Online Measurement of Microalgae Concentration within a Photo-Bioreactor
- On-line monitoring of large cultivations of microalgae and cyanobacteria
- Production cost of a real microalgae production plant and strategies to reduce it
- Life cycle assessment of biodiesel production from microalgae in ponds
- The potential of carbon dioxide capture and sequestration with algae
- A comprehensive life cycle analysis of cofiring algae in a coal power plant as a solution for achieving sustainable energy
- Design and performance of a low-cost, automated, large-scale photobioreactor for microalgae production
- A review on machine learning approaches for microalgae cultivation systems
- Algae Biofuel Global Market Report 2025
- Algae Biofuel Market Size, Share, and Industry Analysis By End-User (Transportation, Aviation, and Others), and Regional Forecast, 2025-2032

Annexes

Annex I. Critical Watch Factors (CWF)
Annex II. Value Chain

Annex I. Critical Watch Factors (CWF)

PEST+(SW)OT	Opportunities	Threats
Political	Marine Conservation & Policy Support	Regulatory & Policy Barriers (Marine farming laws, renewable energy policies)
Economic	Growing Carbon Credit Market	Market Competitiveness (Other renewables like solar/wind may dominate investments)
Social	Rising Demand for Sustainable Energy	Environmental Risks (Potential ecosystem disruption, biodiversity concerns)
Technological	Advancements in Automation & AI for Algae Monitoring	Technology Adaptation Challenges (High cost of implementation, maintenance issues)

Annex II. Value Chain (I)

Microalgae Cultivation ❯ Cultivation Systems ❯ Harvesting & Processing ❯ Biofuel Conversion

Microalgae Selection

- **High-potential strains:** Three types of microalgae with significant potential are:
    - *Chlorella vulgaris*
    - *Nannochloropsis*
    - *Scenedesmus*
- **Key advantages:** These strains stand out for their efficient CO_2 absorption and high potential for biofuel production.
- **Selection factors:** When choosing a microalgae strain, the following are considered:
    - Growth rate: How quickly the microalgae grows.
    - Lipid content: The amount of oils produced, important for biofuel production.
    - Carbon fixation efficiency: How much CO_2 the microalgae can absorb and utilize.

Annex II. Value Chain (II)

Microalgae Cultivation › **Cultivation Systems** › Harvesting & Processing › Biofuel Conversion

Three main systems for cultivating microalgae are:

- **Open Ponds:**
  - Advantages: This method is cost-effective and consumes less energy.
  - Disadvantages: It has contamination risks and depends on weather conditions (such as sunlight and temperature).
- **Photobioreactors (PBRs):**
  - Advantages: They provide a controlled environment, allowing for higher productivity and quality of the culture.
  - Disadvantages: They require a high initial investment and are energy-intensive.
- **Hybrid Systems:**
  - Advantages: They combine the best of open ponds and photobioreactors, optimizing growth and reducing costs.
  - Disadvantages: They are more complex to operate due to the combination of technologies.

Annex II. Value Chain (III)

Microalgae Cultivation > Cultivation Systems > **Harvesting & Processing** > Biofuel Conversion

Methods used to collect and process microalgae after cultivation:

- **Centrifugation**:
  - How it works: Uses centrifugal force to separate microalgae from the growth medium.
  - Advantages: Fast processing with high recovery efficiency.
  - Disadvantages: High energy consumption, making it costly.
- **Flocculation**:
  - How it works: Chemicals (like alum or ferric chloride) or bio-flocculants (like chitosan or bacterial bioflocculants) are added to make microalgae clump together, making them easier to collect.
  - Advantages: Effective for large volumes and can be cost-efficient.
  - Disadvantages: May require additional steps to remove flocculating agents.

Annex II. Value Chain (IV)

Microalgae Cultivation > Cultivation Systems > **Harvesting & Processing** > Biofuel Conversion

Methods used to collect and process microalgae after cultivation:

- **Filtration**:
  - How it works: Uses membranes with varying pore sizes to separate microalgae from the growth medium.
  - Advantages: Suitable for larger microalgae and can be efficient.
  - Disadvantages: Less effective for very small microalgae and can be prone to clogging.
- **Lipid Extraction**:
  - How it works: Various techniques are used to extract lipids (oils) from the microalgae, including:
    - Solvent-based extraction. Uses solvents to dissolve and extract lipids.
    - Mechanical pressing, Physically presses the microalgae to release oils.
    - Enzymatic extraction. Uses enzymes to break down cell walls and release lipids.
  - Purpose: Lipids are essential for biofuel production.

Annex II. Value Chain (V)

Microalgae Cultivation › Cultivation Systems › Harvesting & Processing › **Biofuel Conversion**

Processes used to convert microalgae into biofuels:

- **Transesterification**:
  - <u>How it works</u>: A chemical reaction where triglycerides (lipids) react with alcohol (like methanol) in the presence of a catalyst to produce biodiesel.
  - <u>Efficiency</u>: Yields biodiesel with 96–98% conversion efficiency, meeting industry standards.
- **Hydrothermal Liquefaction**:
  - <u>How it works</u>: Converts wet microalgae biomass directly into bio-oil under high temperature (250–374°C) and pressure (10–25 MPa).
  - <u>Advantages</u>:
    - No need to dry the biomass, saving energy.
    - Yields 35–65% bio-oil with a high heating value.
    - The aqueous phase contains recyclable nutrients for cultivation.
  - <u>Applications</u>: Produces bio-oil that can be used as a renewable fuel.

Annex II. Value Chain (VI)

Microalgae Cultivation › Cultivation Systems › Harvesting & Processing › **Biofuel Conversion**

Processes used to convert microalgae into biofuels:

- **Pyrolysis**:
  - How it works: Rapidly heats microalgae biomass to high temperatures (400–600°C) in an oxygen-free environment, breaking it down into bio-oil, syngas, and biochar.
  - Applications: Produces bio-oil and other byproducts that can be used as energy sources.
- **Gasification**:
  - How it works: Partially oxidizes microalgae biomass at very high temperatures (800–1000°C) to produce syngas (a mixture of hydrogen (H_2), carbon monoxide (CO), and methane (CH_4)).
  - Applications: Syngas can be used as a fuel or further processed into other chemicals.