



Algal Fuel Research in Korea

Ji-Won Yang

Dept. of Chemical and Biomolecular Engineering
KAIST



Contents

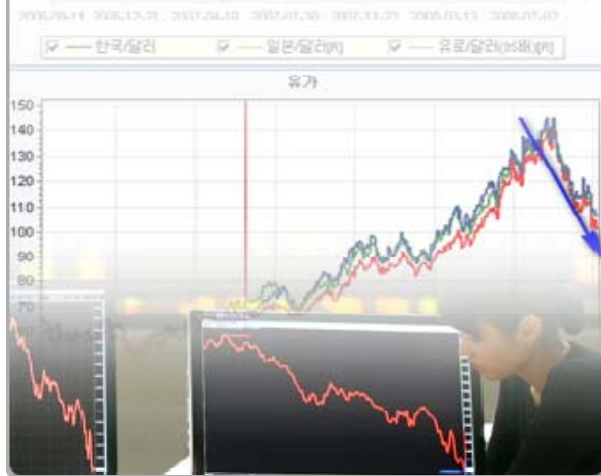
- ❖ Climate Change & Energy Crisis
- ❖ Solutions for the Problem
- ❖ Global Research Trend
- ❖ Algal Fuel Research in Korea
- ❖ Breakthrough of Algal Fuel
- ❖ Conclusion

Climate Change & Energy Crisis

Fossil Fuel

Energy Crisis

High Oil Price
Energy Security Risk



Climate Change

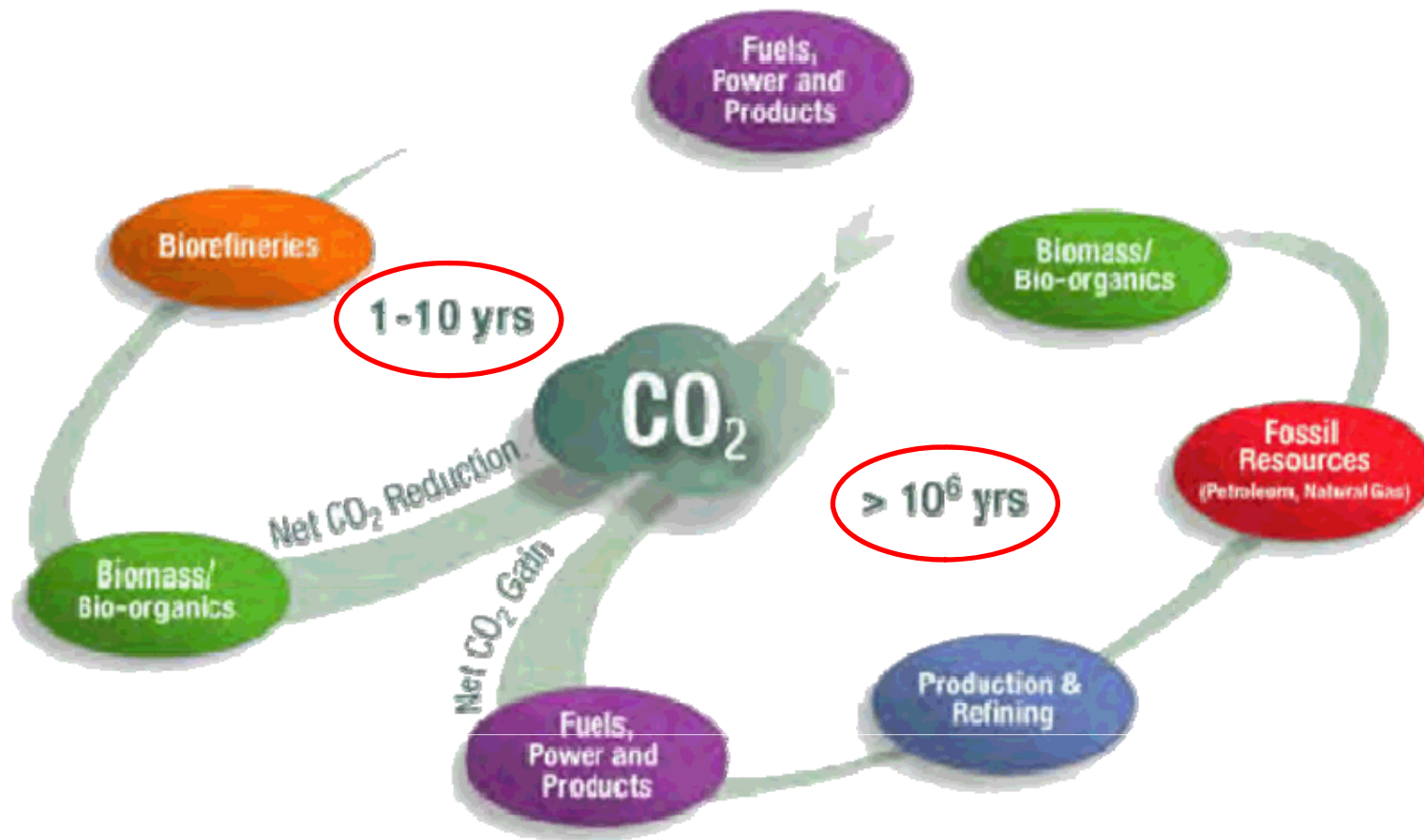
Global Warming
Temperature Rise
Sea Level Rise



Solution for Climate & Energy Crisis

❖ Biofuel

- Short carbon life cycle
- Substitution of fossil fuel



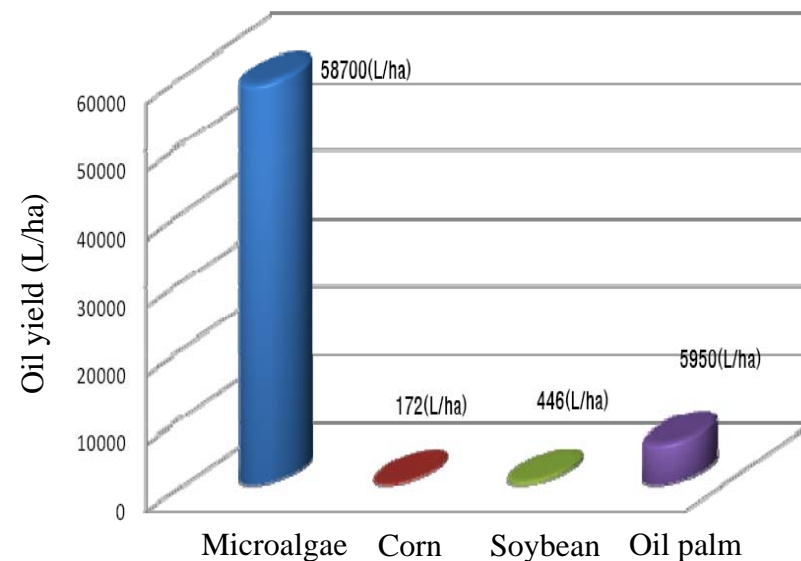
Solutions for the Problem

- ❖ Algal biofuel – Alternative to biofuel from land plants
 - Greenhouse gas reduction – Renewable feedstock
 - Carbon neutral
 - No competition with food crop
 - High oil yield > 100x those for land plants
 - Biodegradable

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change

Timothy Searchinger,^{1*} Ralph Heimlich,² R. A. Houghton,³ Fengxia Dong,⁴ Amani Elobeid,⁴ Jacinto Fabiosa,⁴ Simla Tokgoz,⁴ Dermot Hayes,⁴ Tun-Hsiang Yu⁴

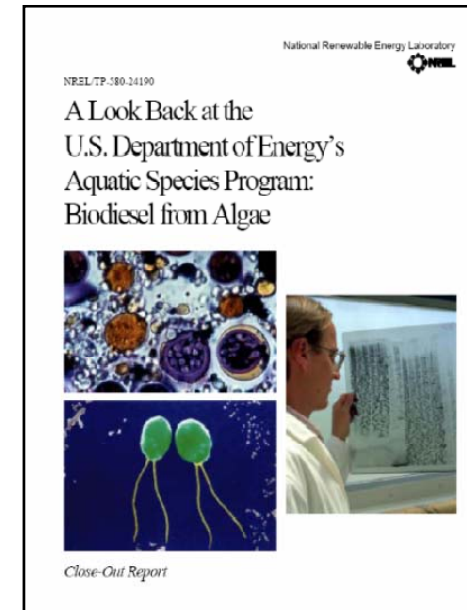
Most prior studies have found that substituting biofuels for gasoline will reduce greenhouse gases because biofuels sequester carbon through the growth of the feedstock. These analyses have failed to count the carbon emissions that occur as farmers worldwide respond to higher prices and convert forest and grassland to new cropland to replace the grain (or cropland) diverted to biofuels. By using a worldwide agricultural model to estimate emissions from land-use change, we found that corn-based ethanol, instead of producing a 20% savings, nearly doubles greenhouse emissions over 30 years and increases greenhouse gases for 167 years. Biofuels from switchgrass, if grown on U.S. corn lands, increase emissions by 50%. This result raises concerns about large biofuel mandates and highlights the value of using waste products.



Global Research Trend

❖ Past Microalgal Research at NREL

- U.S. DOE's Aquatic Species Program (ASP, 1978-1996)
 - 3,000 strains of algae collected and screened
 - Develop renewable transportation fuels from algae
 - Produce biodiesel from microalgae with high lipid contents in open pond (1000 m²)
 - High cost estimates for algal lipids (\$40-\$70/barrel oil)
 - Important resource for algae researchers worldwide



Global Research Trend

❖ Current Microalgal Research at NREL

- Colorado Center for Biorefining and Biofuels (collaboration between NREL and Colorado School of Mines)
 - Bioenergy-focused microalgae strain collection
- Collaborative Research and Development Agreement (CRADA) under Chevron/NREL Alliance
 - Algae strains that can be economically harvested and processed into finished transportation fuels
- Laboratory Directed Research and Development
 - High-throughput technique for assessing lipid production in algae
 - Novel gene sequencing technology for high-throughput transcriptomics analysis of microbial strains used for biofuel production

Global Research Trend

❖ RITE (Research Institute of Innovated technology for Earth, Japan)

The Biological CO₂ Fixation and Utilization Project by RITE(1) THE BIOLOGICAL CO₂ FIXATION AND UTILIZATION PROJECT BY RITE (2)
— Highly-effective Photobioreactor System — - Screening and Breeding of Microalgae with High Capability in Fixing CO₂ -

Naoto Usui, Masahiro Ikenouchi

Masakazu Murakami and Masahiro Ikenouchi

- Biological CO₂ fixation and utilization project by microalgae (1990-1999)
 - Developed highly effective photobioreactor system
 - closed photobioreactor using optic fiber
 - Sunlight collection & transmission system
 - Applied to LNG power plant
 - 70% conversion rate of CO₂ to microalgal biomass
 - Production of fuel oil from *Botryococcus* sp.
 - : 10,400 kcal/kg

Global Research Trend

- ❖ International Network on Biofixation of CO₂ and Greenhouse Gas Abatement with Microalgae
 - Biological CO₂ fixation project
 - Started operation in June, 2002.
 - Manager: Dr. Benemann (Inst. for Environ. Management)
 - US DOE, Eni Technologie (Italy), Exxon Mobil, etc.
 - Biodiesel production (*Botryococcus* sp.)
 - Research goal
 - Doubled productivity in mass cultivation of microalgae (50→100 DCW ton/ha/year in favorable climatic conditions)
 - CO₂ reduction: 100 ton CO₂/ha of algal pond

Algal Fuel Research in Korea (1)

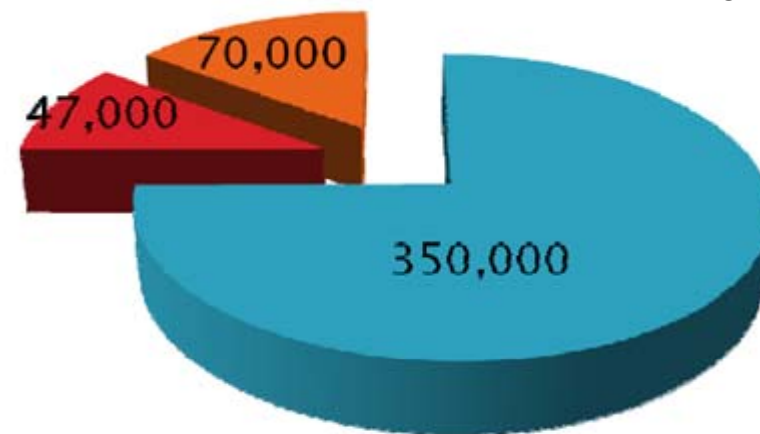
❖ CDRS (Carbon Dioxide Reduction & Sequestration R&D Center)

- Ministry of Education, Science and Technology
 - KRIBB (Korea Research Institute of Bioscience and Biotechnology)
- Period : 2002-2012 (10 years in 3 phases)
- CO₂ fixation with microalgae and biodiesel production



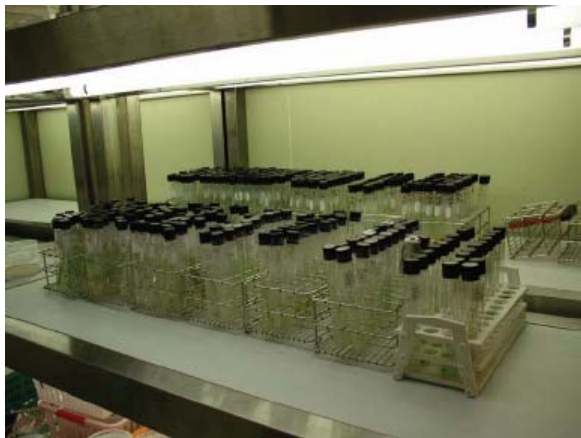
■ Government ■ Private (cash) ■ Private (spot)

Unit : \$



Algal Fuel Research in Korea (1)

❖ Microalgae Screening and Identification



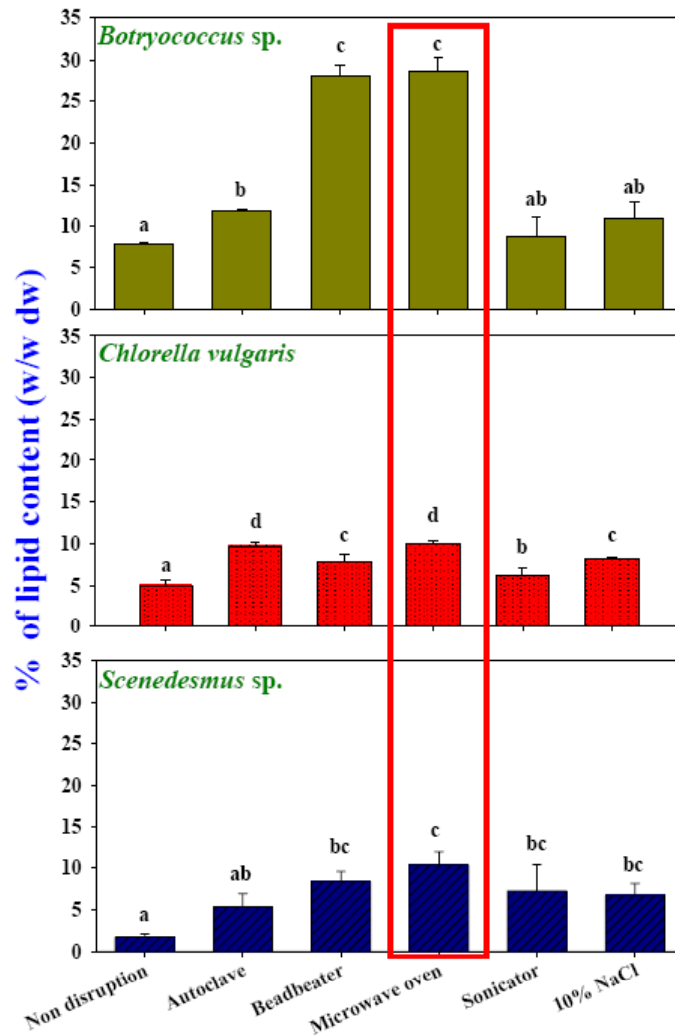
Microalgal strains

Accessible microalgal strains through BRC

Taxonomy	Habitat	Capacity
Cyanophyceae	Freshwater & seawater	188
Chlorophyceae	Freshwater & seawater	339
Charophyceae	Seawater	23
Bacillariophyceae	Freshwater & seawater	45
Chrysophyceae	Freshwater & seawater	2
Xanthophyceae	Freshwater	2
Cryptophyceae	Seawater	7
Euglenophyceae	Freshwater & seawater	3
Rhodophyceae	Freshwater & seawater	2
Total		611

Service by BRC-Web site : <http://www.brc.re.kr>

Algal Fuel Research in Korea (1)



❖ High efficient lipid extraction method
- Microwave oven

- For *Botryococcus sp.*
 - Bead-beating (28.1%)
: difficult to scale-up
 - Microwave oven (28.6%)
- For *C. vulgaris*
 - Autoclaving and microwave oven
: highest efficiency
 - Bead-beating (7.9%)
- For *Scenedesmus sp.*
 - Microwave oven
: highest efficiency

Algal Fuel Research in Korea (2)

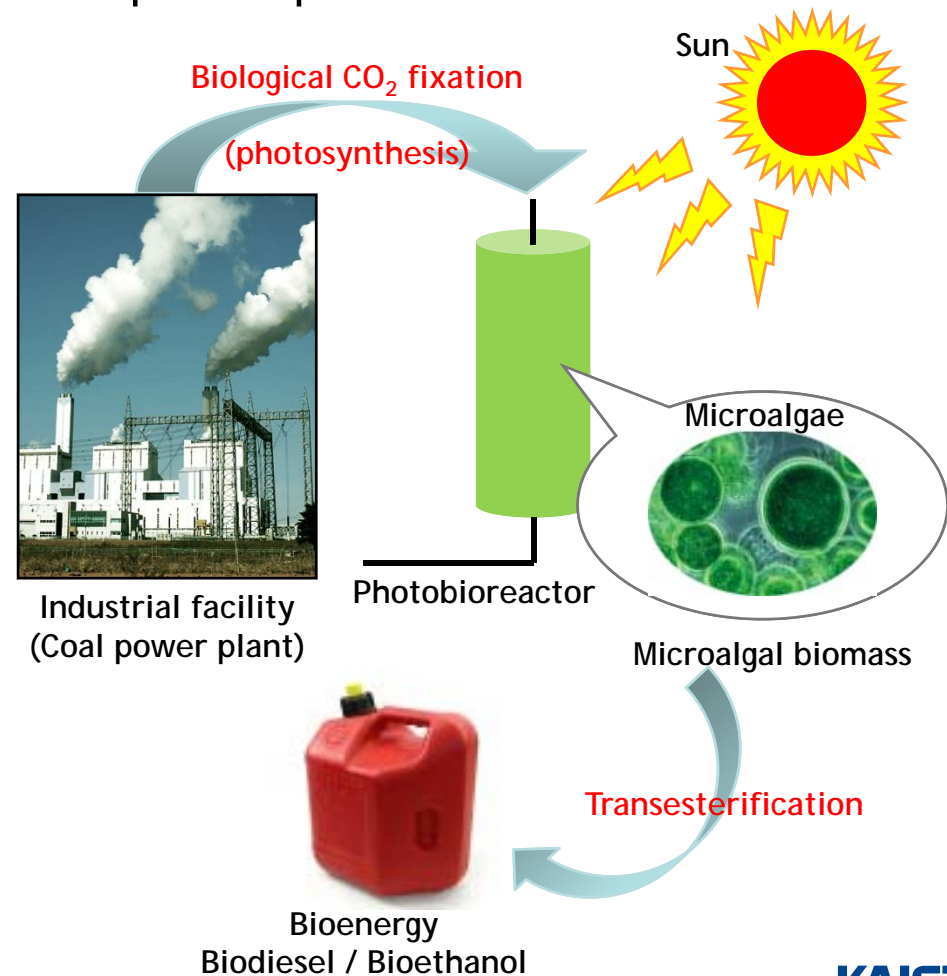
❖ Planning of R&D : Bioenergy Technology Master Plan using Marine Biomass

- Ministry of Land, Transport and Maritime Affairs
 - Inha University
- Period : 2008-2009 / 2009-2018
- Total fund : \$ 200 million
- Biofuel production using microalgae and macroalgae

Algal Fuel Research in Korea (2)

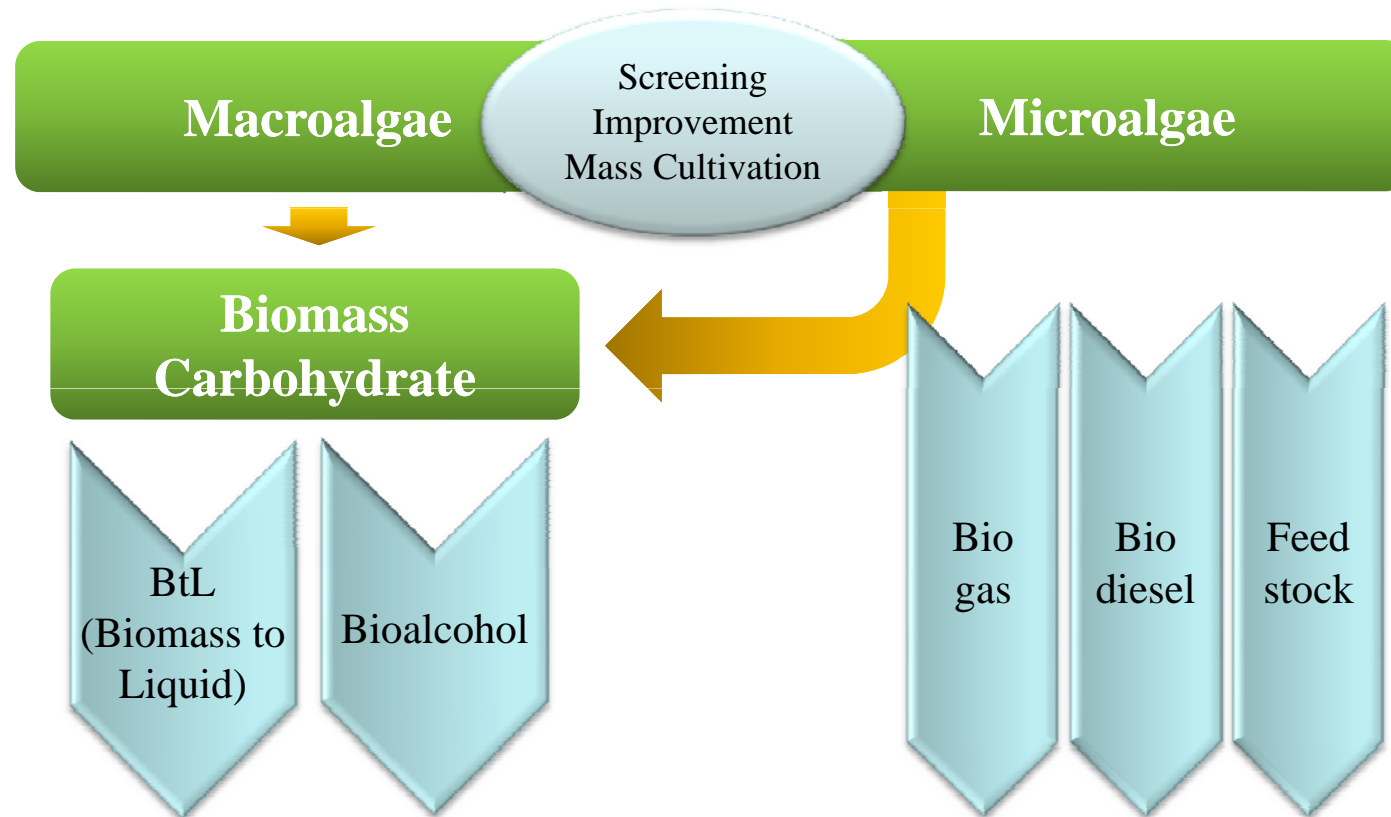
❖ Condition of location

- Mass cultivation : utilization of power plants on the coast



Algal Fuel Research in Korea (2)

❖ Strategy of Research



Selection of Optimum Site / Economical Feasibility / Wastewater Treatment

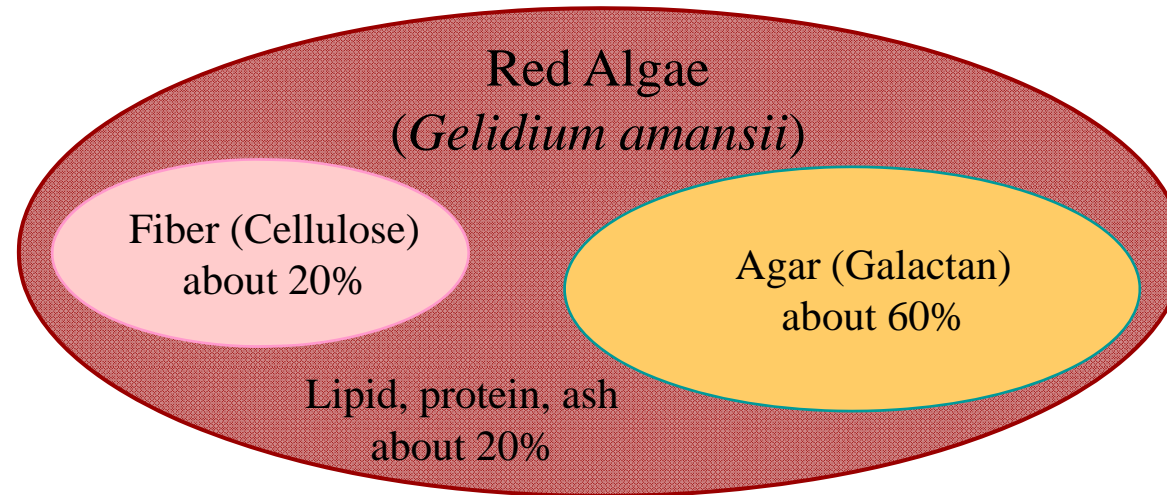
Algal Fuel Research in Korea (3)

❖ Development of Bioethanol Production Technology from Red Algae

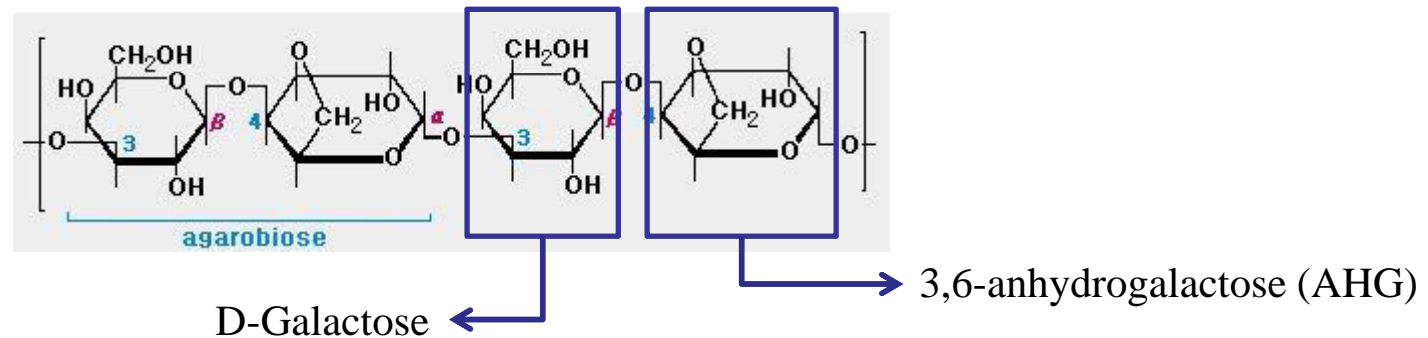
- KITECH (Korea Institute of Industrial Technology)
- Period : 2008-2011
- Feedstock : 2 million ha of farm until 2018
- Commercialization of bioalcohol until 2013
- Production of 1.9 billion L of bioalcohol until 2018

Algal Fuel Research in Korea (3)

❖ Compositional Analysis of Red Algae

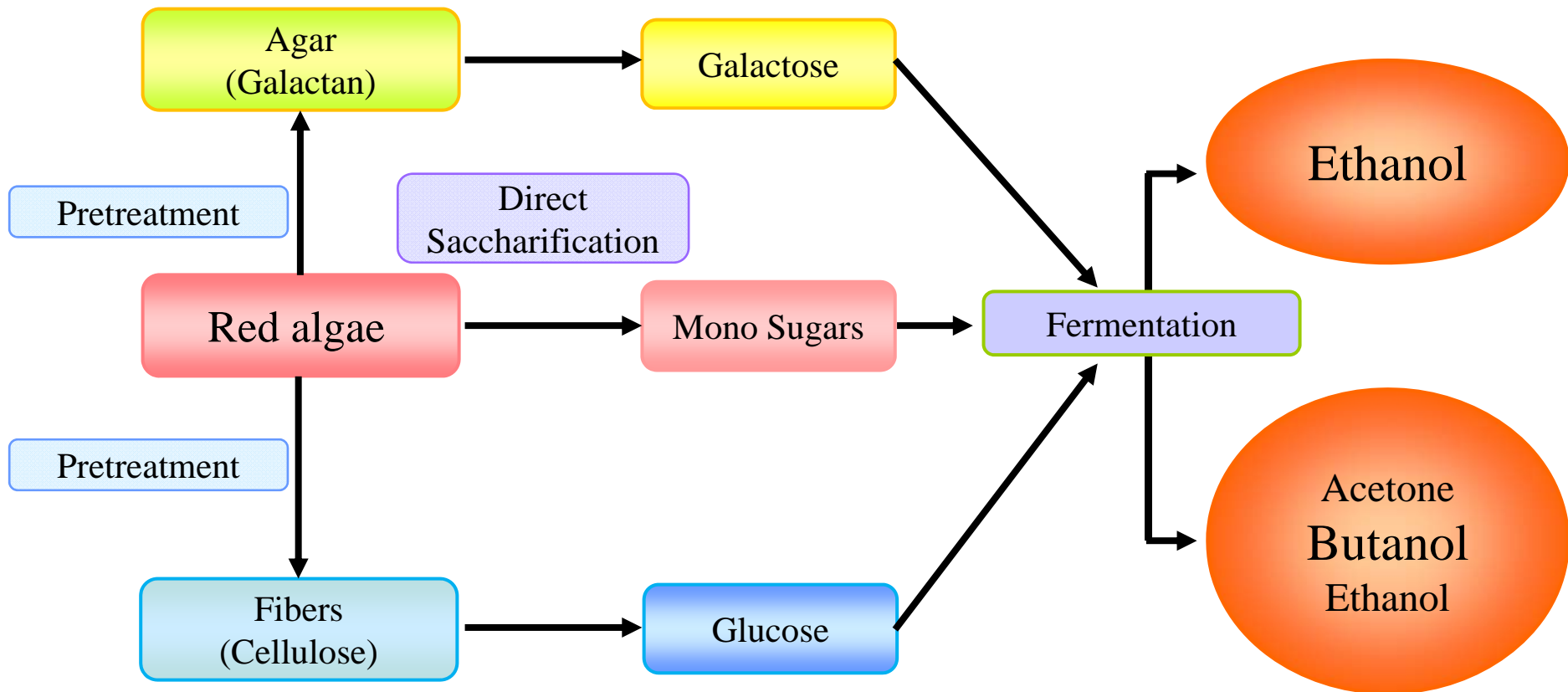


- Galactan structure : D-Galactose + 3,6-anhydrogalactose (AHG)



Algal Fuel Research in Korea (3)

❖ Simple Process



Algal Fuel Research in Korea (3)

- ❖ Technical Hurdles : Economical Feedstock by Marine Aquaculturing
 - Tropical region
 - Plenty of sunshine, warm temp., low labor cost, etc.



Algal Fuel Research in Korea (3)

❖ Technical Hurdles : Effective Depolymerization

- Depolymerization of galactose-based mixed sugars
- Minimization of byproduct (5-HMF) formation using noble catalyst
- Saccharification of crystalline fiber

❖ Saccharification Experiment

- Condition : 140 ~ 150°C with various acid catalysts
 - Substrate : pulverized *Gelidium amansii*
- Saccharification (Direct) : 51% based on total carbohydrate
- Saccharification (Indirect, Acidic saccharification)
 - Monosugar yields from Agar : 78% based on galactan
 - Monosugar yields from Agar : > 95 % using ionic liquids (IL) with minimized formation of 5-HMF
 - Monosugar yields from Fiber : 61% based on glucan



Total saccharification yield : 59% (without IL), 69% (with IL)

Algal Fuel Research in Korea (4)

- ❖ Biological CO₂ fixation by microalgae (KAIST, 1999-2001)
 - *Chlorella* sp. HA-1 (NIES, Japan)
 - 3L lab-scale photobioreactor

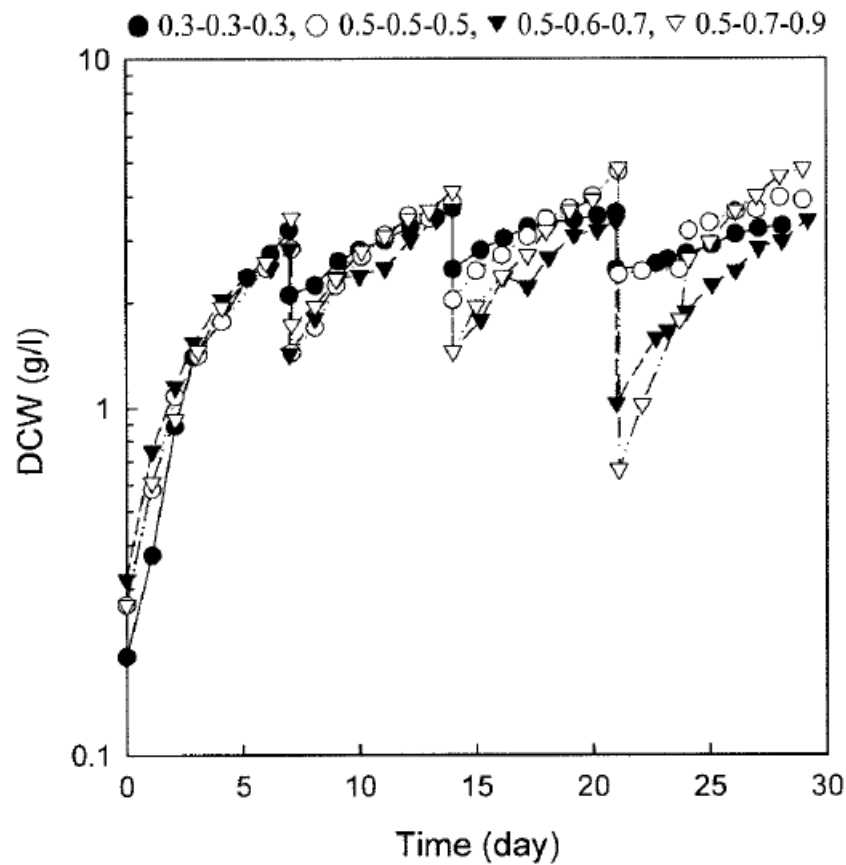
	Operation period (days)	The averaged cell growth rate (g/l-day)	Total amount of fixed CO ₂ (g/day)
Batch	7	0.413	1.320
Semi-Continuous (0.5-0.6-0.7)	30	0.360, 0.321, 0.277, 0.340 (per week)	1.038
Series (4 reactors)	7	0.308, 0.331, 0.250, 0.365 (per reactor)	4.013

- Various operation
 - Batch mode
 - Semi-continuous mode
 - Series mode

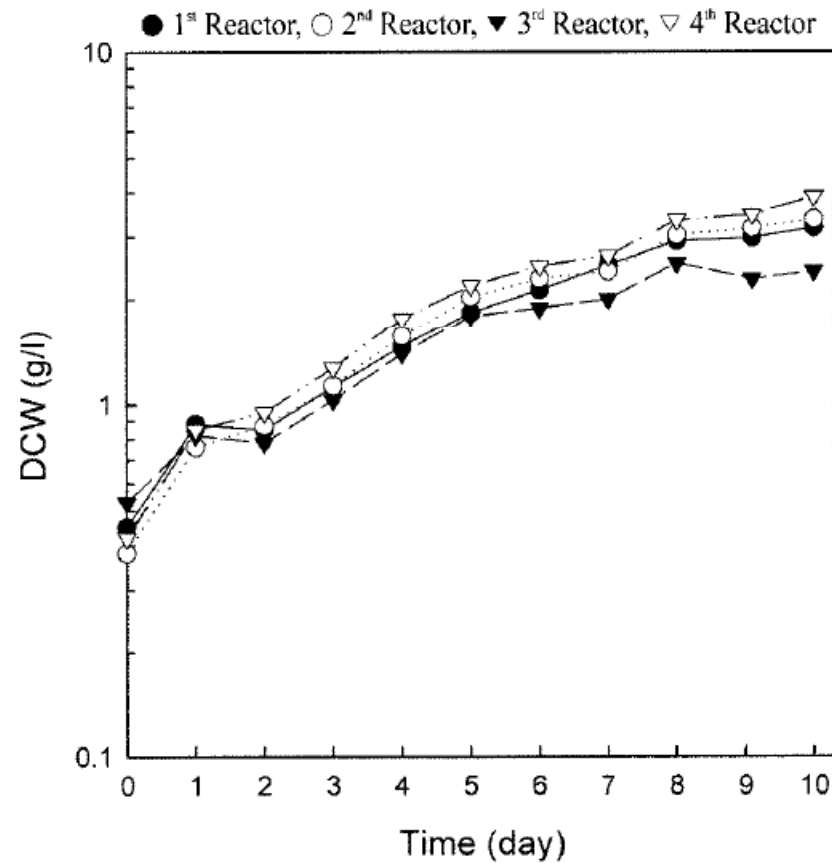


Algal Fuel Research in Korea (4)

❖ Semi-continuous mode

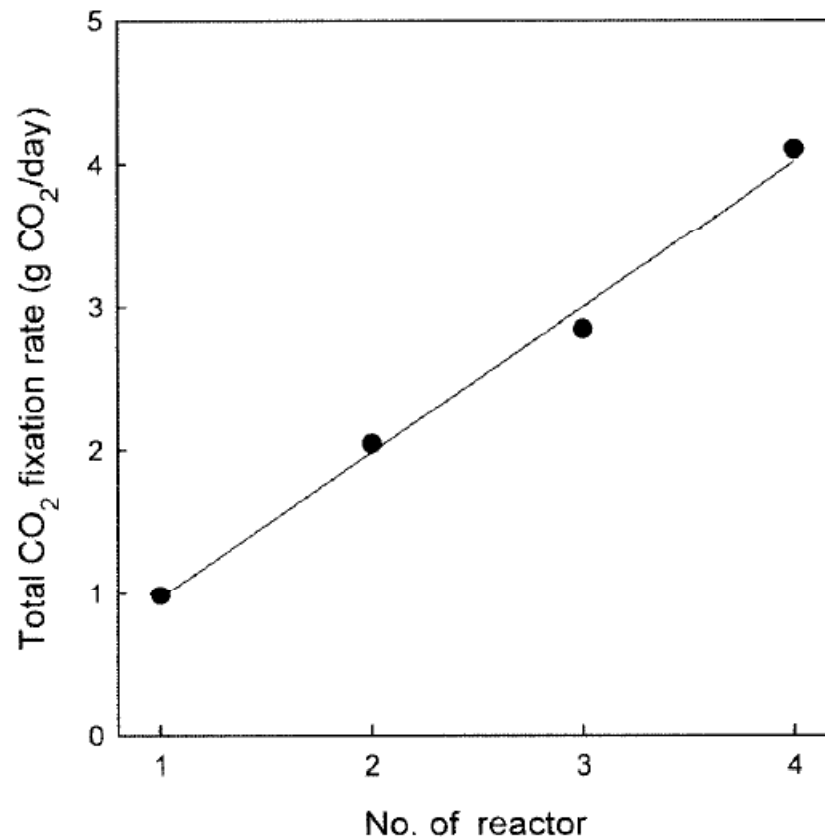


❖ Series mode

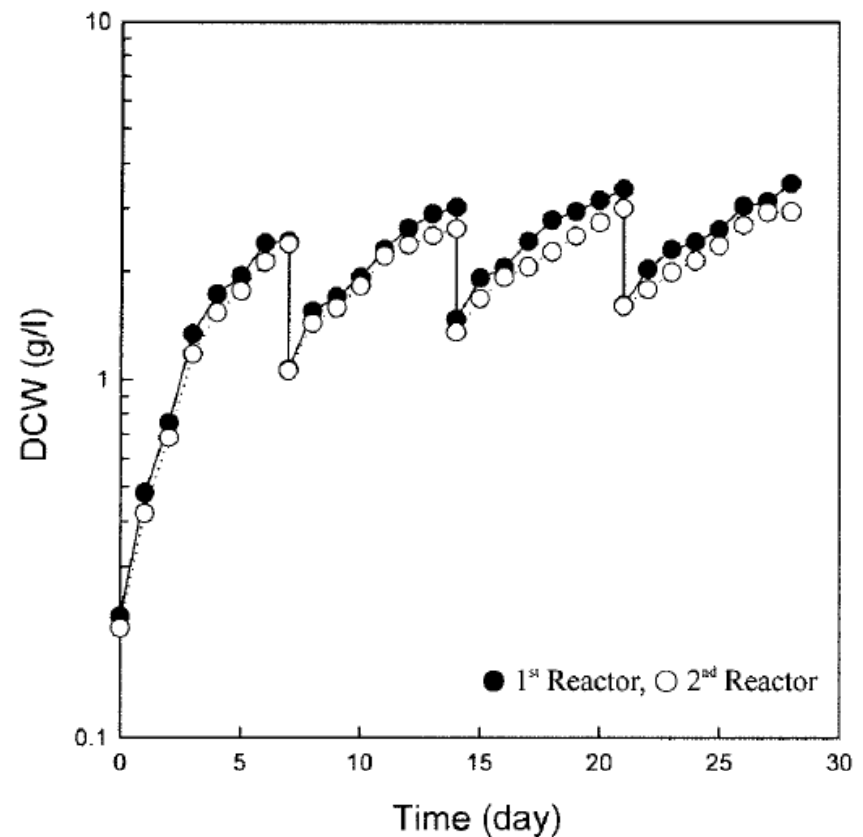


Algal Fuel Research in Korea (4)

- ❖ Correlation of total CO₂ fixation rate and the number of connected reactors



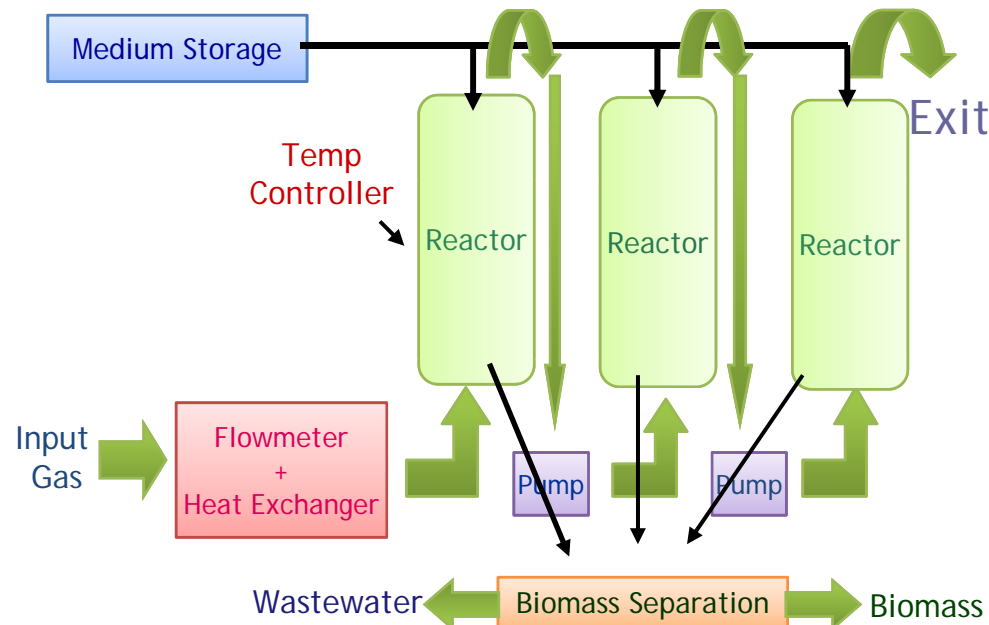
- ❖ Series reactor system of semi-continuous operation



Algal Fuel Research in Korea (4)

❖ Biological CO₂ fixation by microalgae (KAIST, 1999-2001)

- *Chlorella* sp. HA-1 (NIES, Japan)
- 600L pilot-scale photobioreactor
 - Main objective : CO₂ fixation
 - CO₂ fixation rate : 0.562 kg/m²·day
 - Oil contents of *Chlorella* sp. HA-1 : 18.4%



600 L Reactor (pilot-scale)

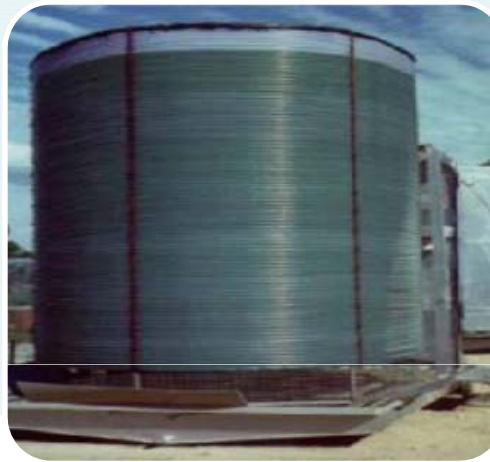


Breakthrough of Algal Cultivation

❖ Conventional Culture System



Tubular photobioreactor
High efficiency
but high cost



Helical photobioreactor
Suitable for small-scale cultivation of microalgal inoculant



Raceway pond
Low operation cost
but low growth yield

Problem : Photoinhibition, Biofilm formation, Higher production cost

Breakthrough of Algal Cultivation

❖ Breakthrough - PBR Design

- High density mass cultivation of microalgae

Light

- Internal light using high efficient light source (LED)
 - Reduction of photoinhibition and heat generation
 - Low electrical energy cost

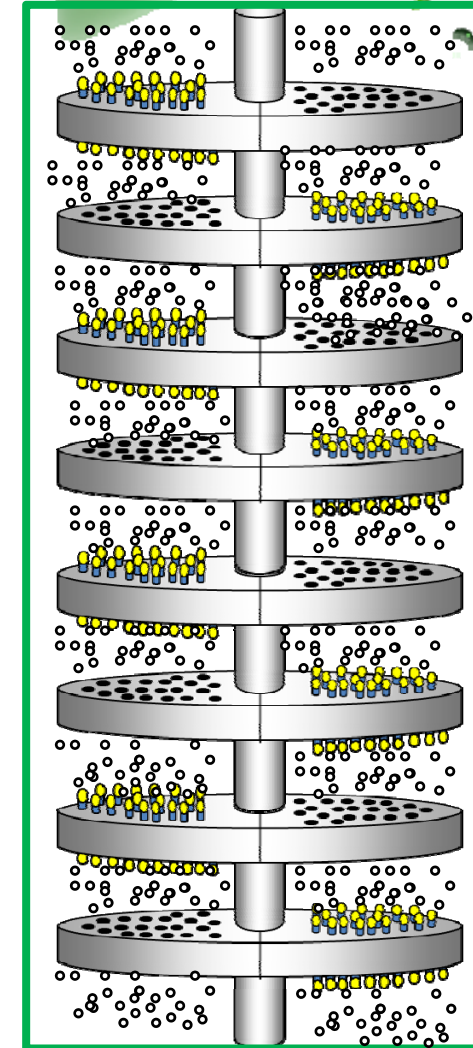
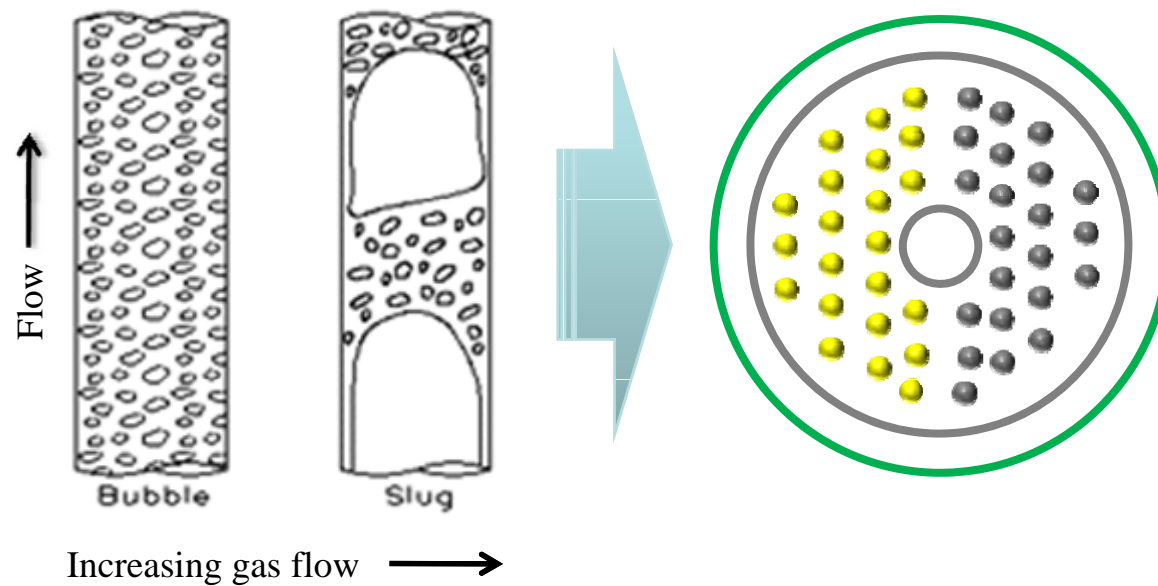
Type

- Bubble column type reactor
 - Improvement of mixing efficiency (baffle, stirrer, etc.)
 - Various operation methods
(batch, semi-continuous, series, etc.)

Breakthrough of Algal Cultivation

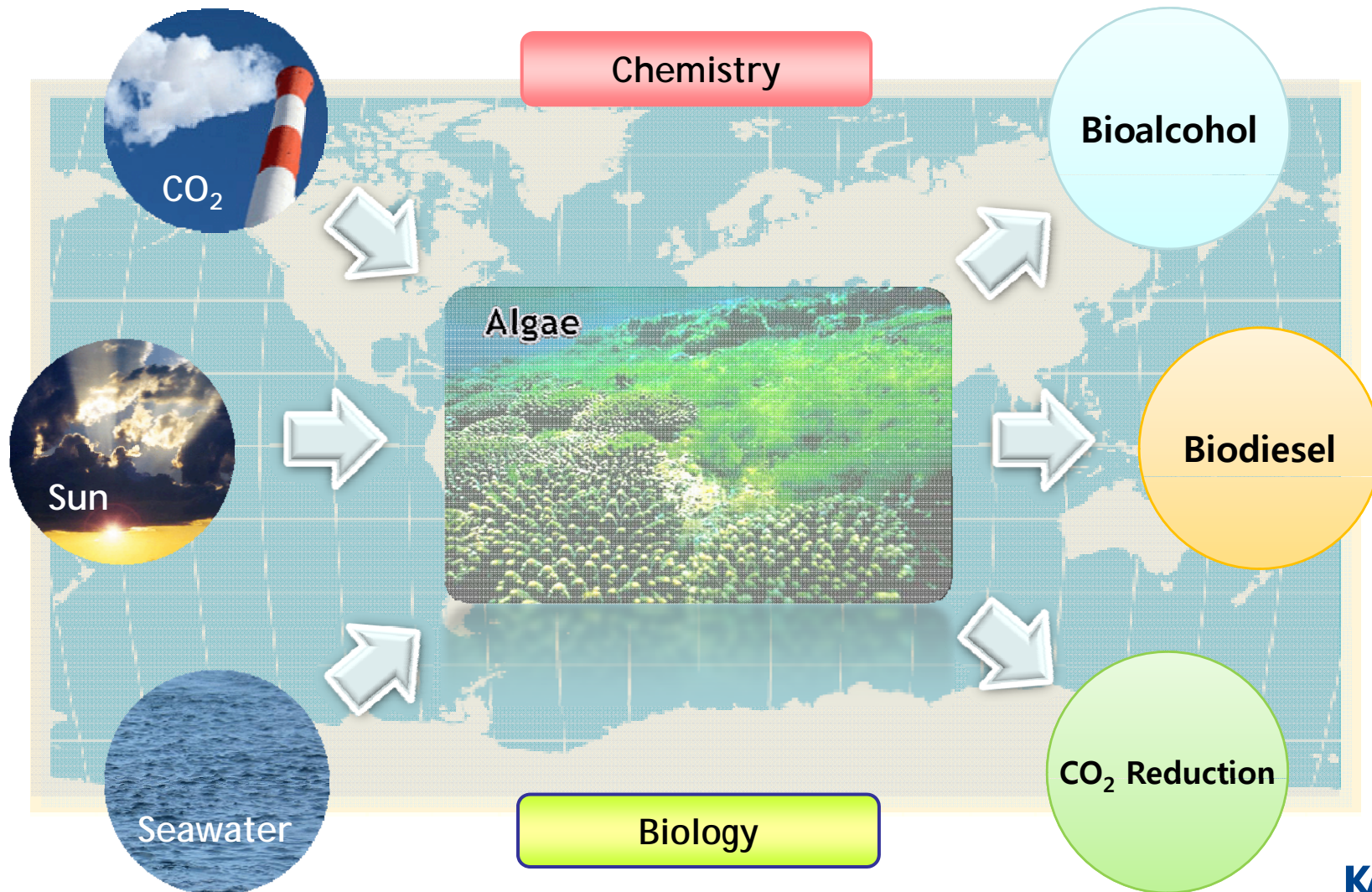
❖ Breakthrough - PBR Design

- Internal LED light
- High gas flow rate → Slug flow
- Baffle design → Decrease of bubble size



Conclusion

❖ Algae as a Solution for Climate and Energy Crisis



A decorative border of vibrant green leaves with water droplets, framing the top and sides of the slide.

Thank You !

jwyang@kaist.ac.kr

KAIST