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

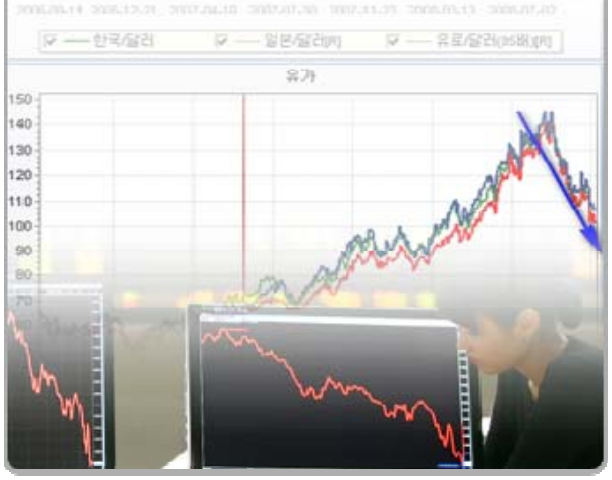
KAIST

Climate Change & Energy Crisis

Fossil Fuel

Energy Crisis

High Oil Price
Energy Security Risk



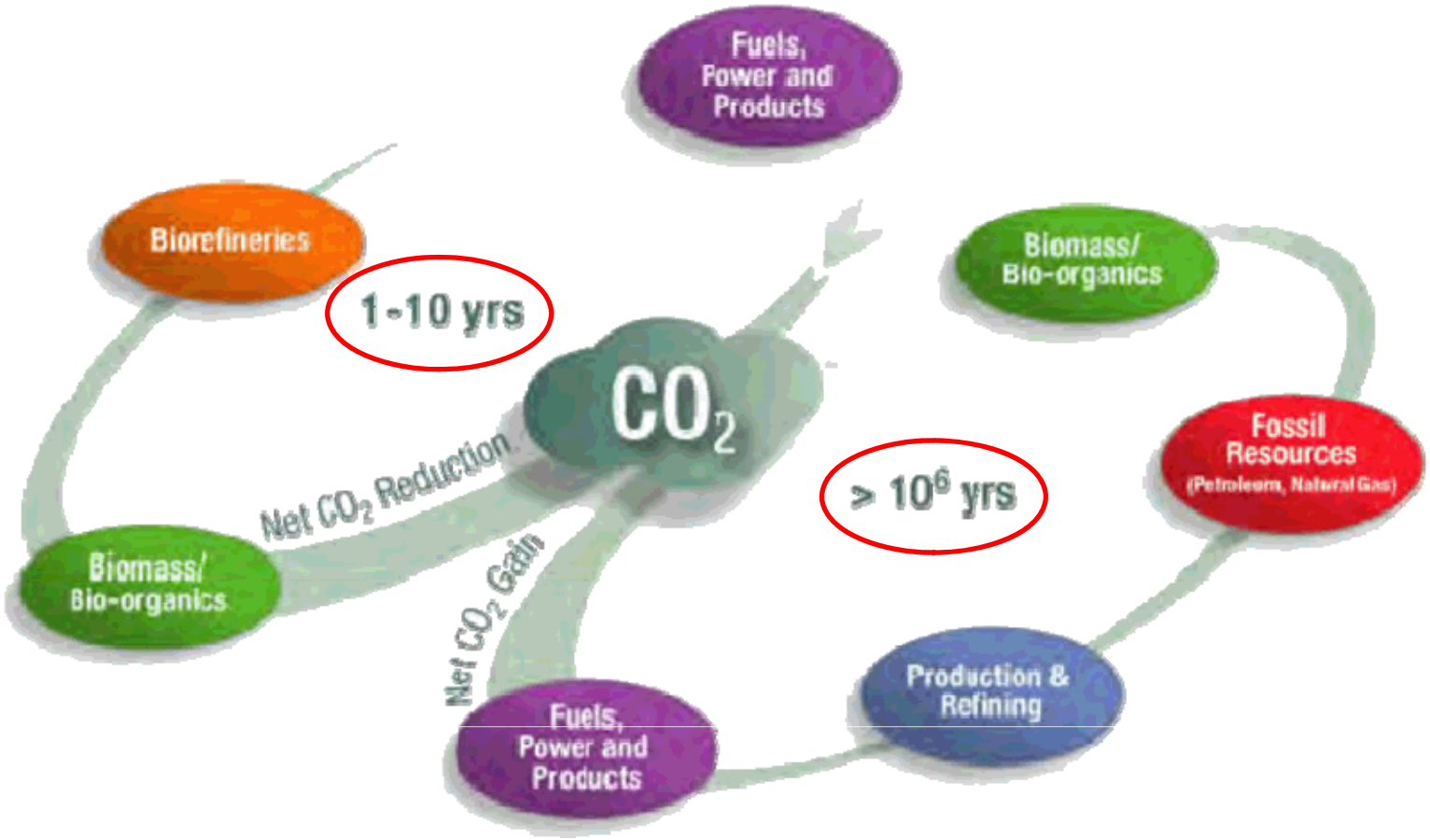
Climate Change

Global Warming
Temperature Rise
Sea Level Rise

KAIST

Solution for Climate & Energy Crisis

- Biofuel
  - Short carbon life cycle
  - Substitution of fossil fuel



KAIST

Science 319, 1238 (2008) / *Biotechnology Advances* 25: 294-306, 2007

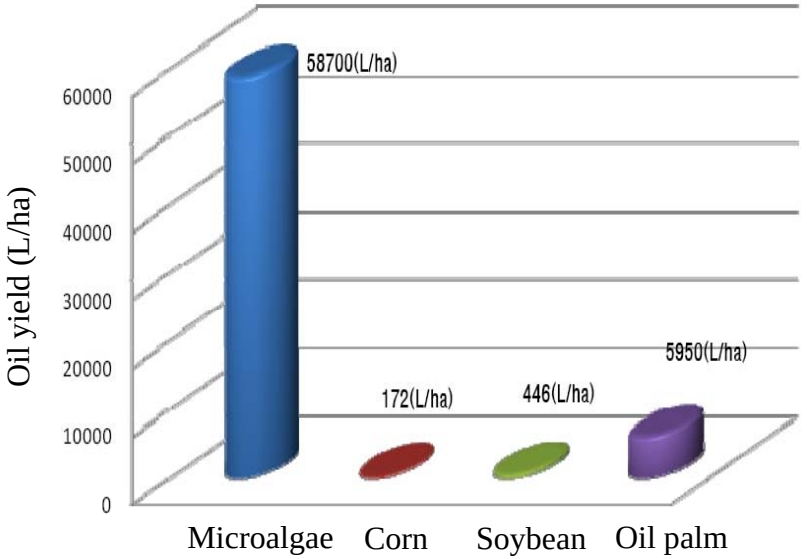
Solutions for the Problem

- 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 Yu[4]

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.

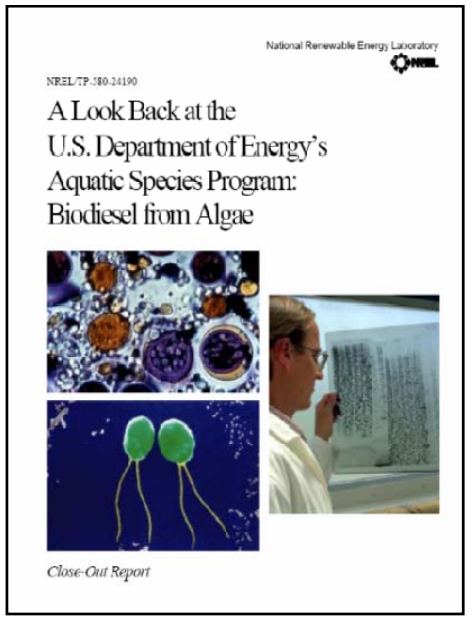


KAIST

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 m^2)
    - High cost estimates for algal lipids ($40-$70/barrel oil)
    - Important resource for algae researchers worldwide



KAIST

http://www.nrel.gov/biomass/proj_microalgae.html

Global Research Trend

- Current Microagal 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

Energy Convers. Mgmt Vol. 38, Suppl., pp. 487-492, 1997 / *Energy Convers. Mgmt* Vol. 38, Suppl., pp. 493-497, 1997

Global Research Trend

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

The Biological CO_2 Fixation and Utilization Project by RITE(1)
— Highly-effective Photobioreactor System —

Naoto Usui, Masahiro Ikenouchi

THE BIOLOGICAL CO_2 FIXATION AND UTILIZATION PROJECT BY RITE (2)
- Screening and Breeding of Microalgae with High Capability in Fixing CO_2 -

Masakazu Murakami and Masahiro Ikenouchi

- Biological CO_2 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 CO_2 to microalgal biomass
  - Production of fuel oil from *Botryococcus* sp.
    : 10,400 kcal/kg

KAIST

http://www.co2captureandstorage.info/networks/Biofixation.htm

Global Research Trend

- International Network on Biofixation of CO_2 and Greenhouse Gas Abatement with Microalgae

  - Biological CO_2 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)
    - CO_2 reduction: 100 ton CO_2/ha of algal pond

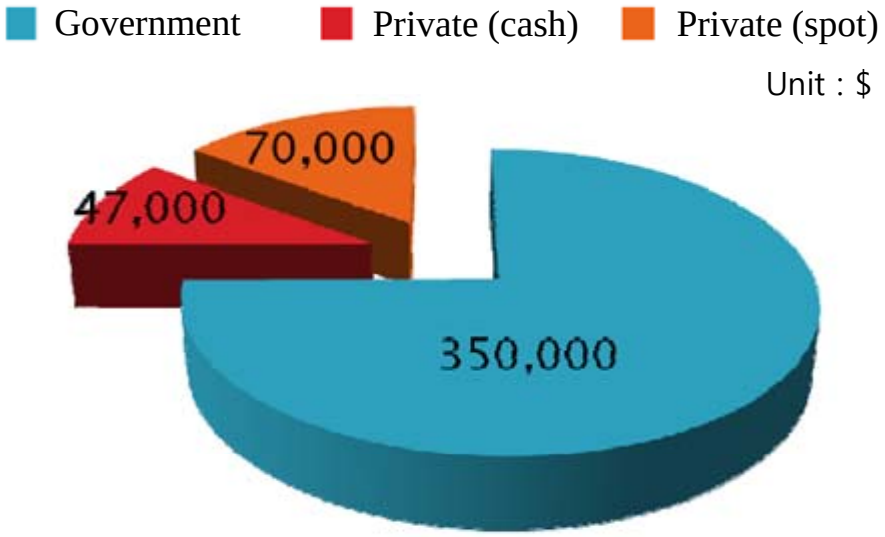
Algal Fuel Research in Korea (1)

❖ 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)
- CO_2 fixation with microalgae and biodiesel production

CDRS
Carbon Dioxide R&D Center

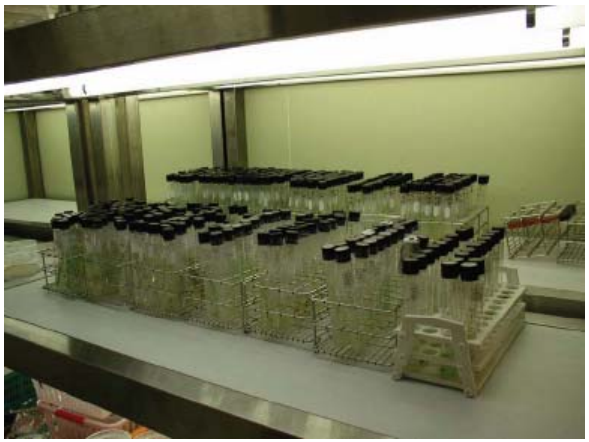
KRIBB 한국생명공학연구원
Korea Research Institute of Bioscience and Biotechnology



KAIST

Algal Fuel Research in Korea (1)

❖ Microalgae Screening and Identification



Microalgal strains

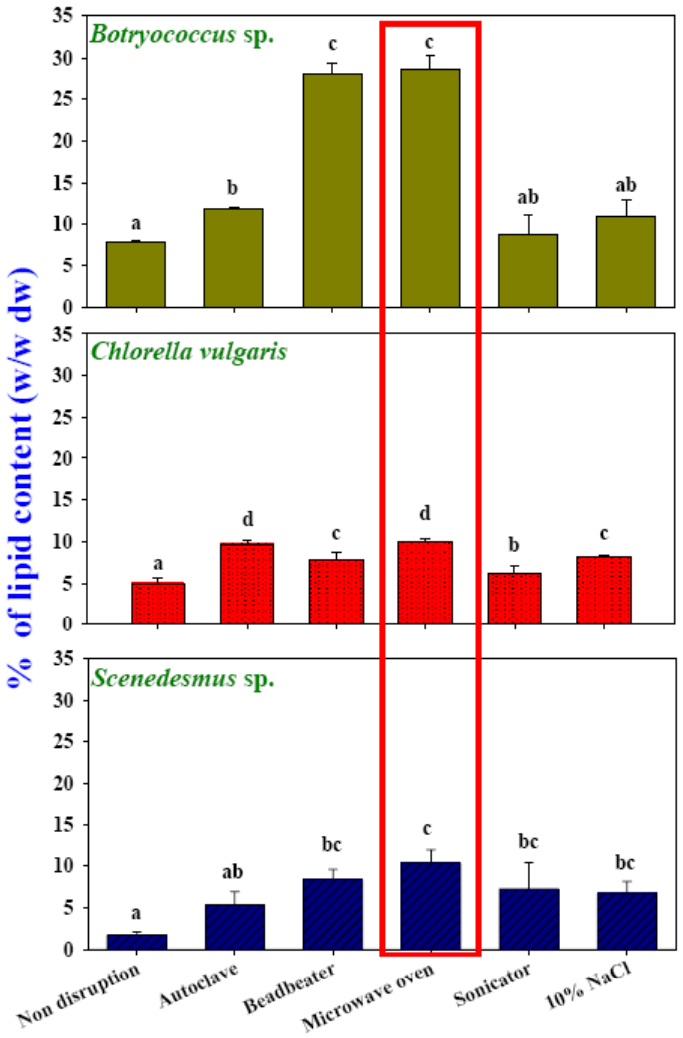
Accessible microalgal strains through BRC

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

Bioresource Technology (2009), Comparison of several methods for effective lipid extraction from microalgae

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

KAIST

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)

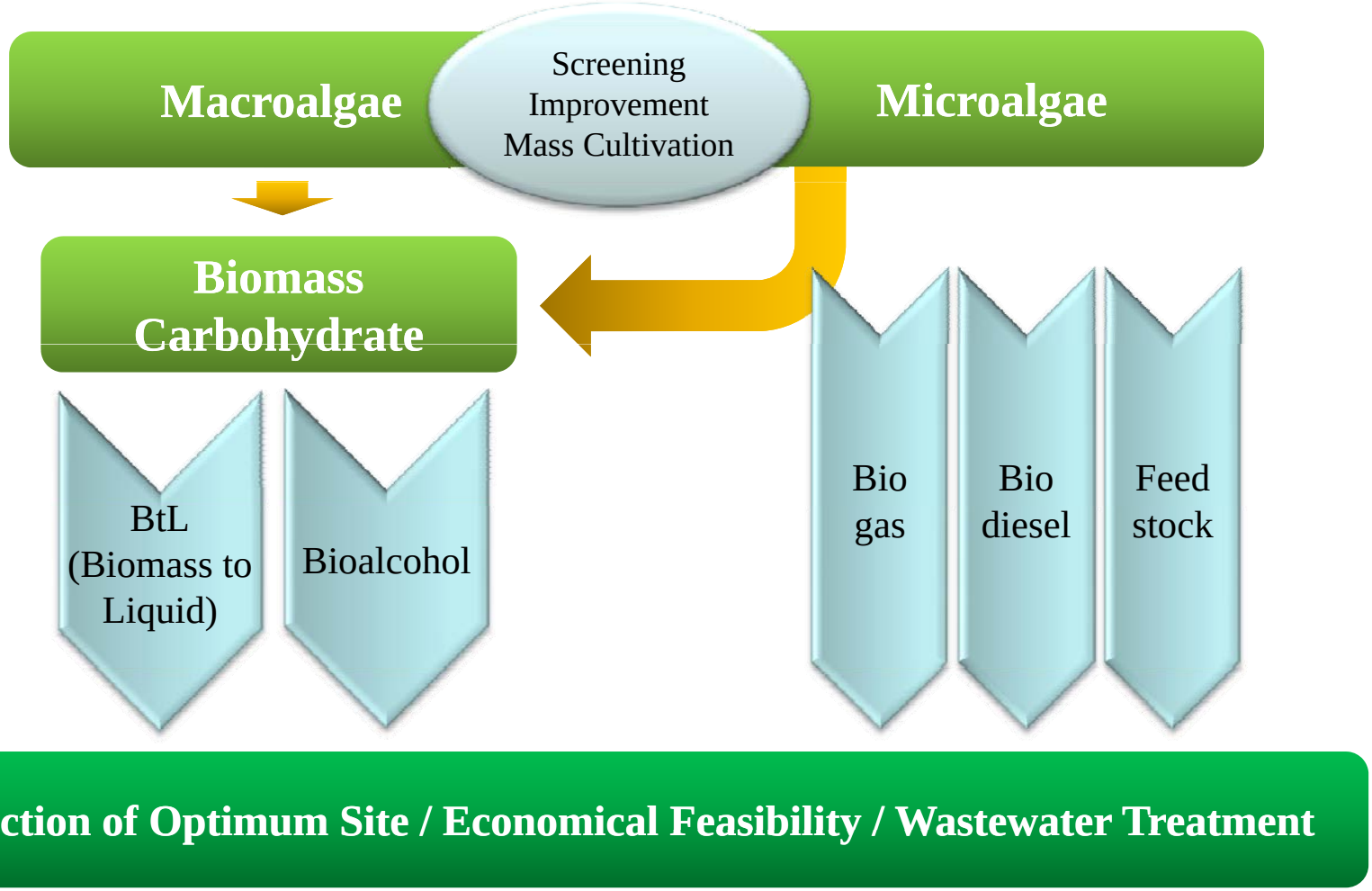
- Condition of location
  - Mass cultivation : utilization of power plants on the coast

Industrial facility
(Coal power plant)

KAIST

Algal Fuel Research in Korea (2)

❖ Strategy of Research



KAIST

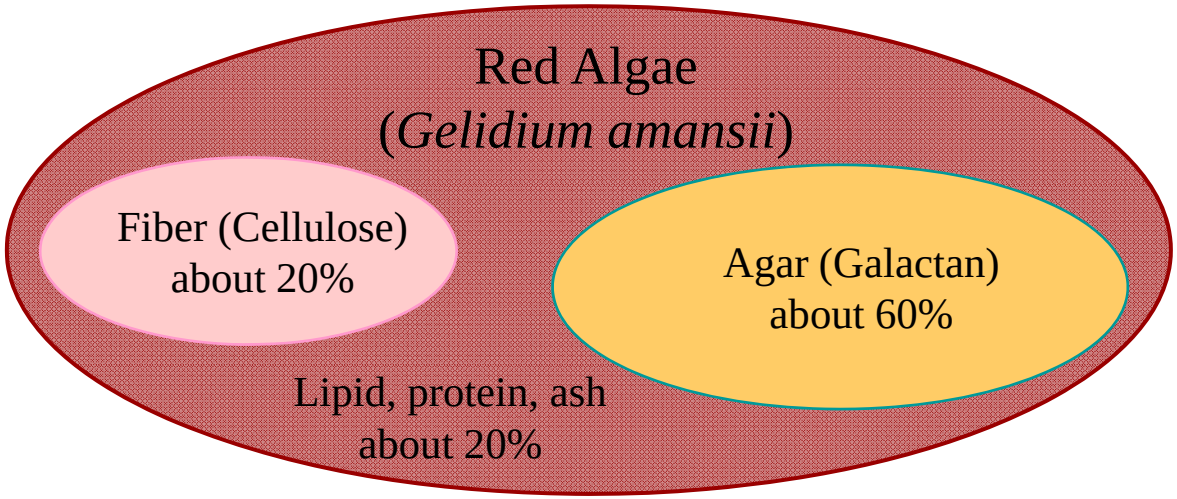
Algal Fuel Research in Korea (3)

❖ Development of Bioethanol Production Technology from Red Algae

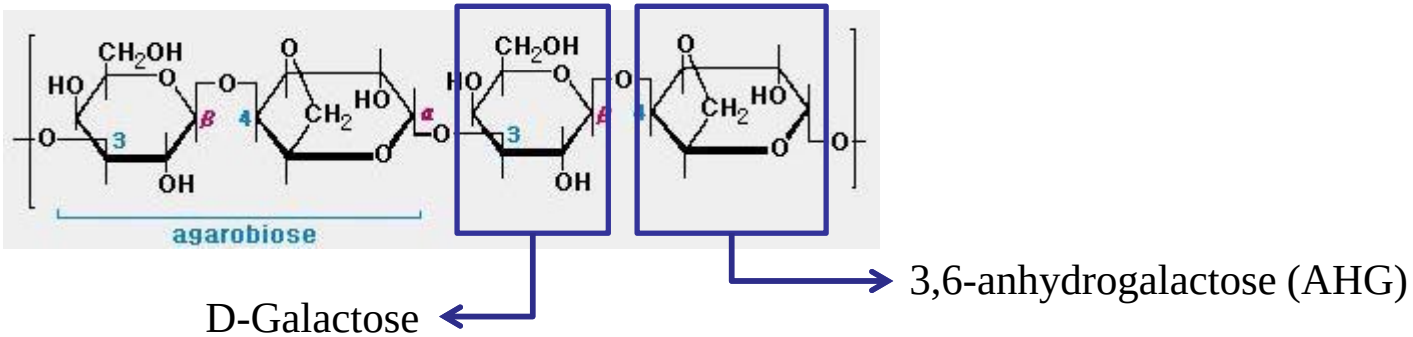
- KITECH (Korea Institute of Industrial Technology)
- Period : 2008-2011
- Feedstock : 2 million ha of farm until 2018
- Commercialization of bioalcohol until 2013
- Production of 1.9 billion L of bioalcohol until 2018

Algal Fuel Research in Korea (3)

❖ Compositional Analysis of Red Algae



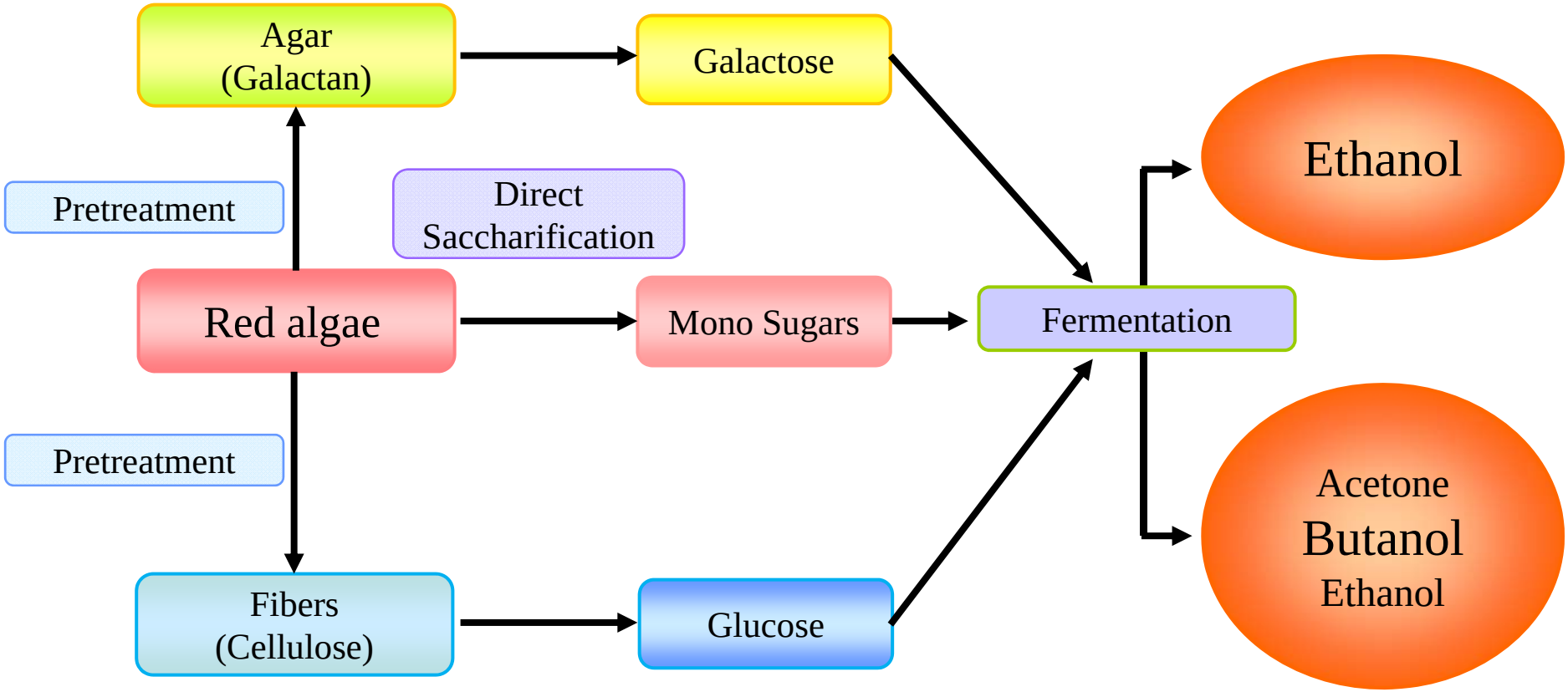
- Galactan structure : D-Galactose + 3,6-anhydrogalactose (AHG)



KAIST

Algal Fuel Research in Korea (3)

❖ Simple Process



KAIST

Algal Fuel Research in Korea (3)

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

KAIST

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℃ 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)

J. Microbiol. Biotechnol. (2005), 15(3), 461-465

Algal Fuel Research in Korea (4)

- Biological CO_2 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

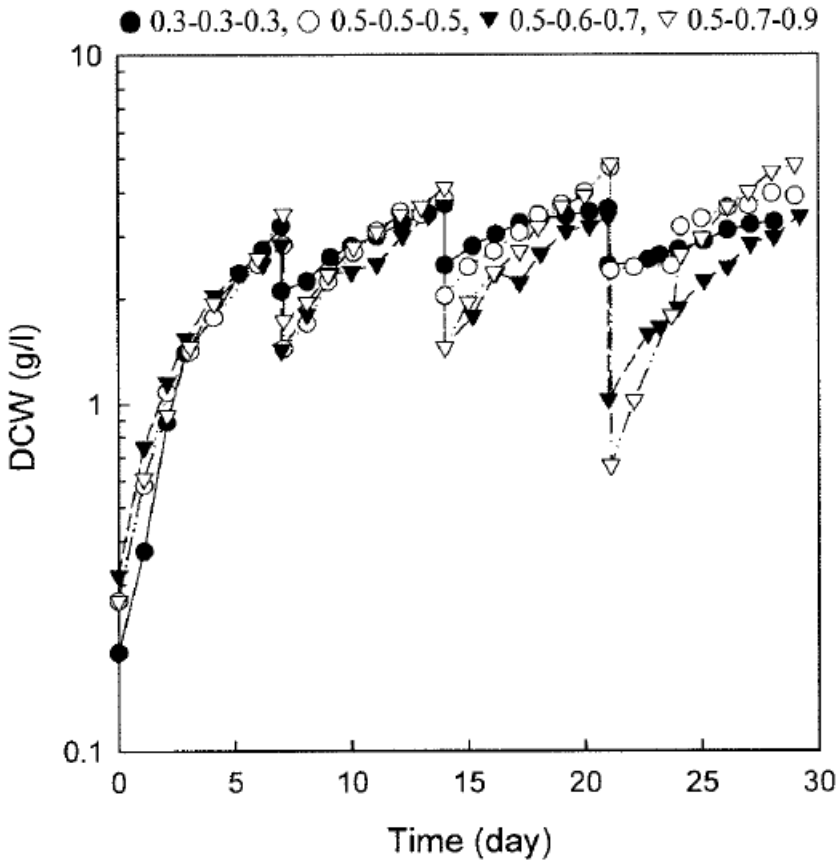
- Various operation
  - Batch mode
  - Semi-continuous mode
  - Series mode

KAIST

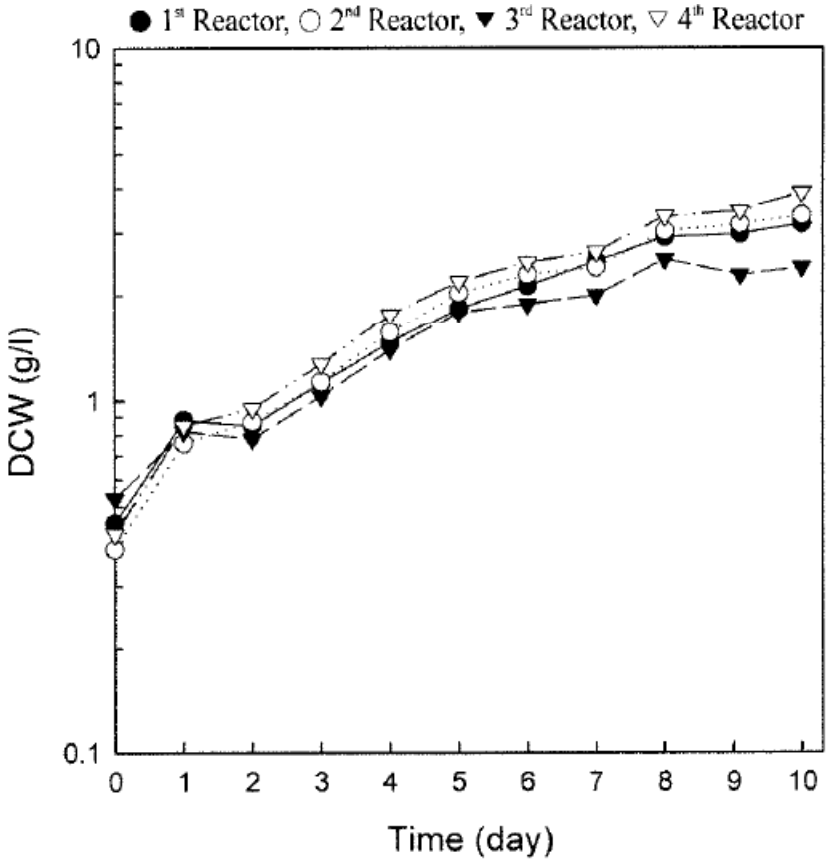
J. Microbiol. Biotechnol. (2005), 15(3), 461-465

Algal Fuel Research in Korea (4)

❖ Semi-continuous mode



❖ Series mode

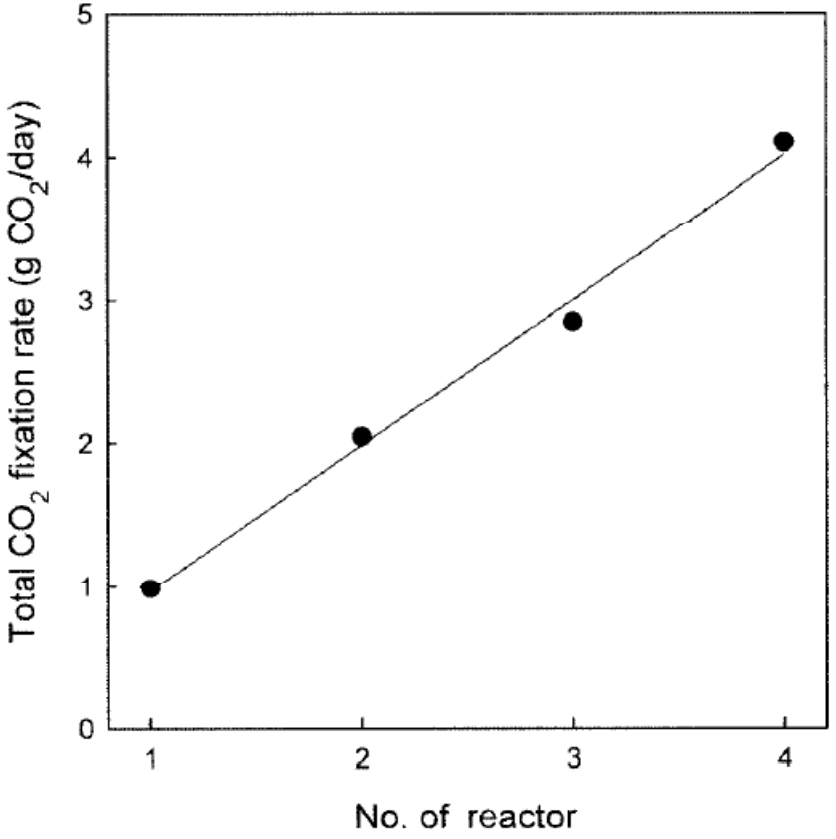


KAIST

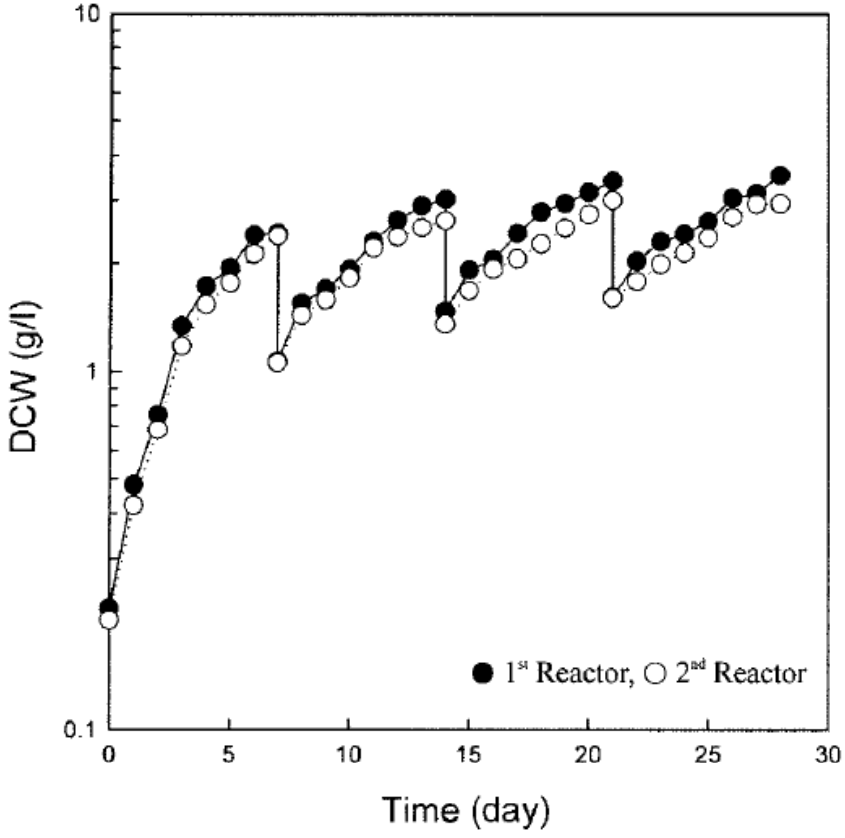
J. Microbiol. Biotechnol. (2005), 15(3), 461-465

Algal Fuel Research in Korea (4)

- Correlation of total CO_2 fixation rate and the number of connected reactors



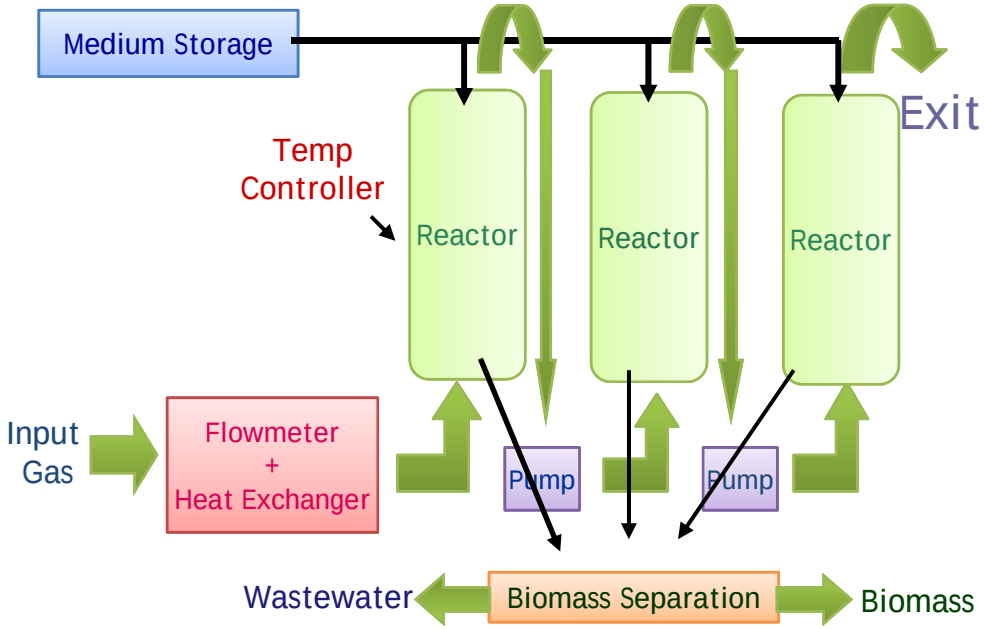
- Series reactor system of semi-continuous operation



KAIST

Algal Fuel Research in Korea (4)

- Biological CO_2 fixation by microalgae (KAIST, 1999-2001)
  - *Chlorella* sp. HA-1 (NIES, Japan)
  - 600L pilot-scale photobioreactor
    - Main objective : CO_2 fixation
    - CO_2 fixation rate : 0.562 kg/m^2·day
    - Oil contents of *Chlorella* sp. HA-1 : 18.4%



600 L Reactor (pilot-scale)

KAIST

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

KAIST

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

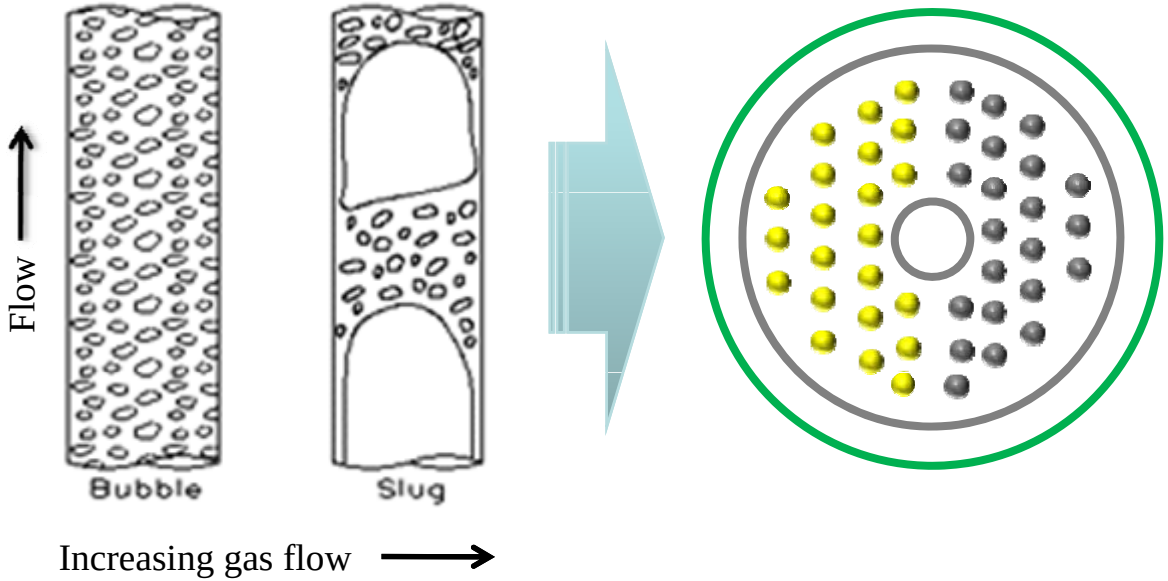
Type

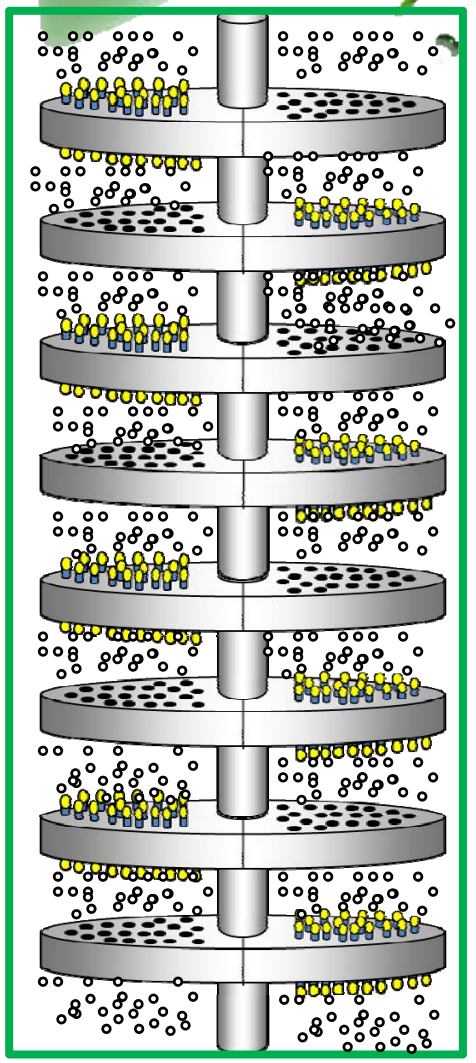
- Bubble column type reactor
  - Improvement of mixing efficiency (baffle, stirrer, etc.)
  - Various operation methods
    (batch, semi-continuous, series, etc.)

http://www.lbgweb.com/articles-news015a.aspx

Breakthrough of Algal Cultivation

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

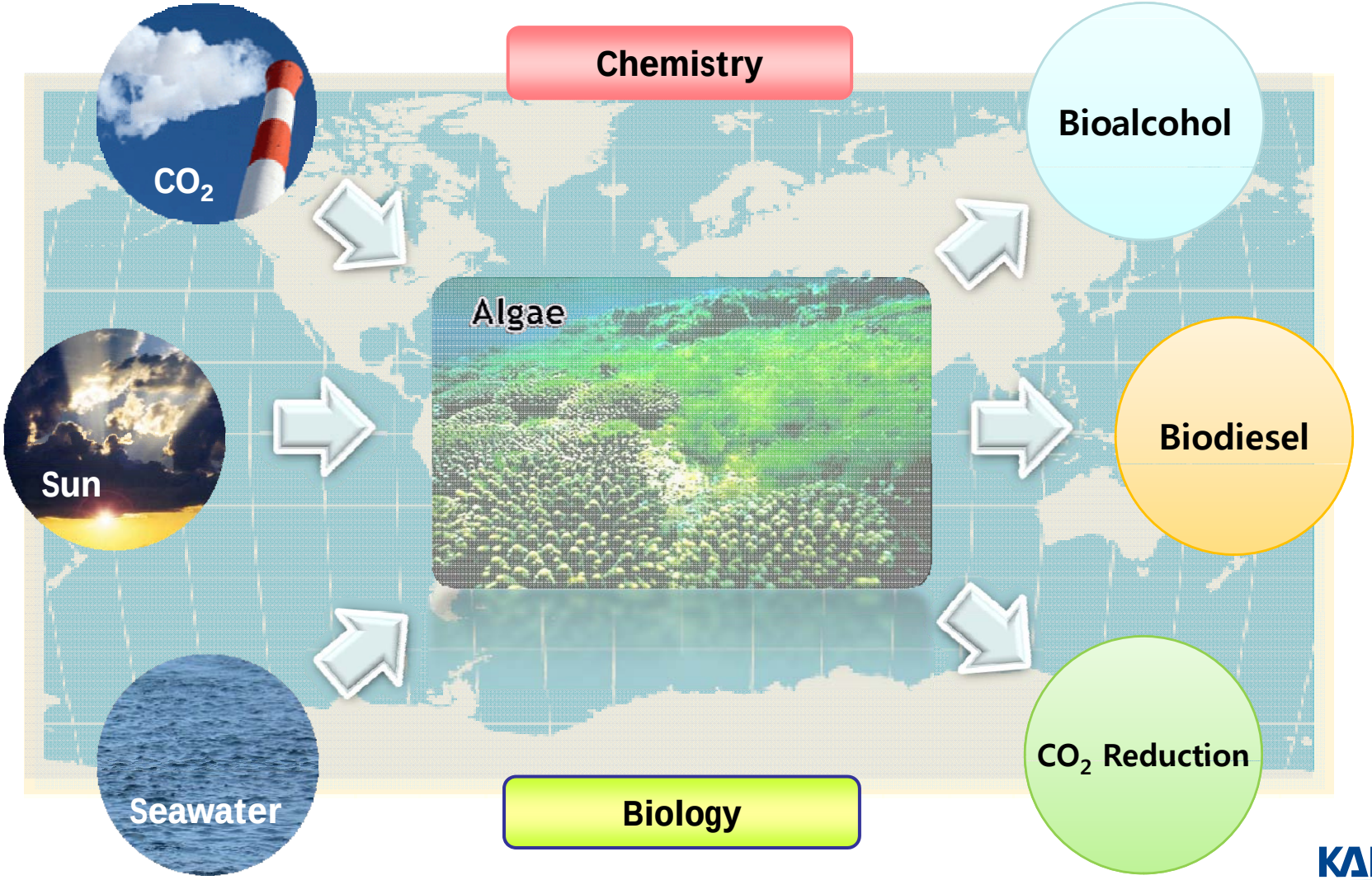




KAIST

Conclusion

- Algae as a Solution for Climate and Energy Crisis



KAIST

Thank You !

jwyang@kaist.ac.kr

KAIST