

SYNTHETIC BIOLOGY FOR MARINE BIOREFINERY: NEW OPPORTUNITY OF AI TECHNOLOGY IN OCEAN INDUSTRY

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Professor

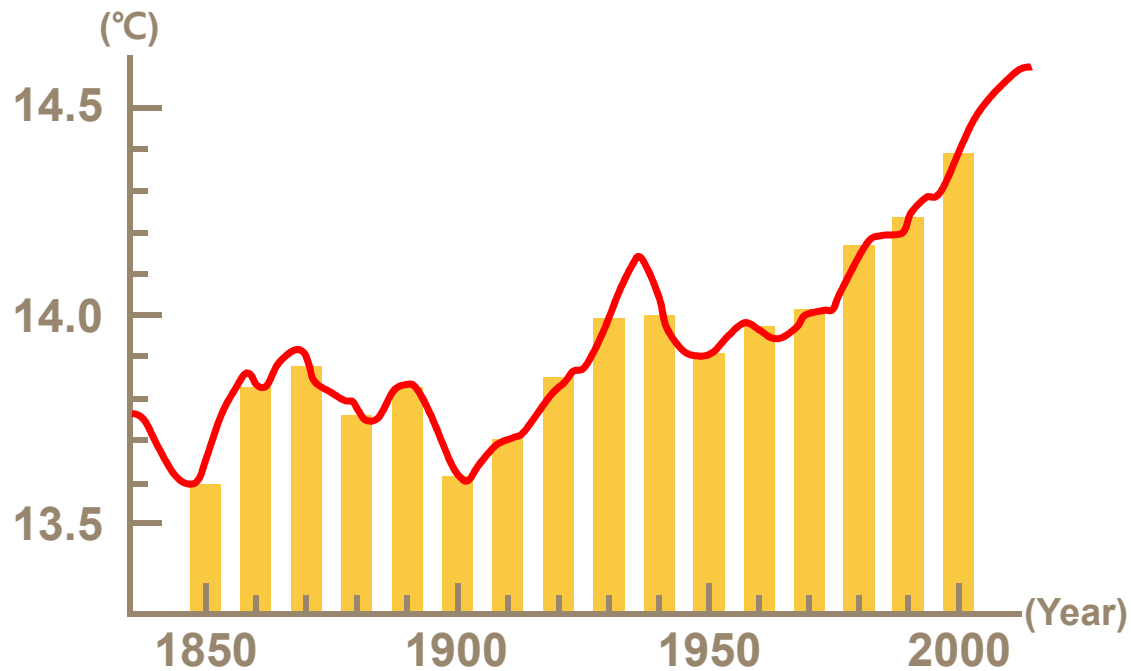
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Carbon Neutrality and Biorefinery

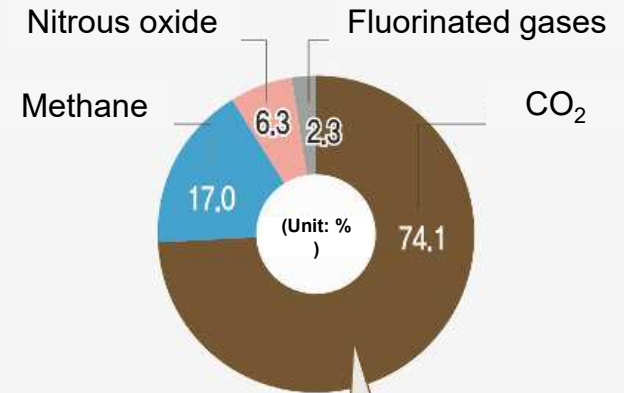
Fossil Fuels (Oil, Coal, Gas, etc.) and Global Warming

Carbon Neutrality and Biorefinery

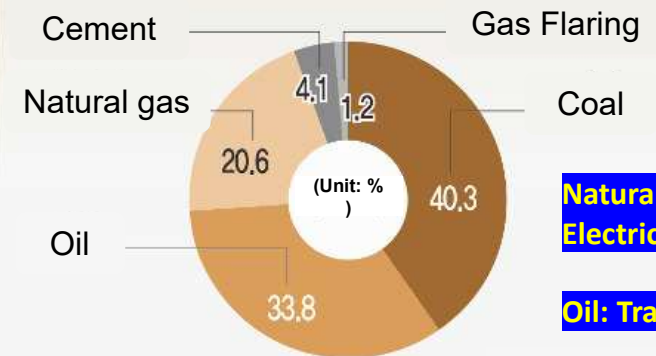


Changes in the Earth's Average Temperature

Global Greenhouse Gas Composition



CO₂ Emissions by Source



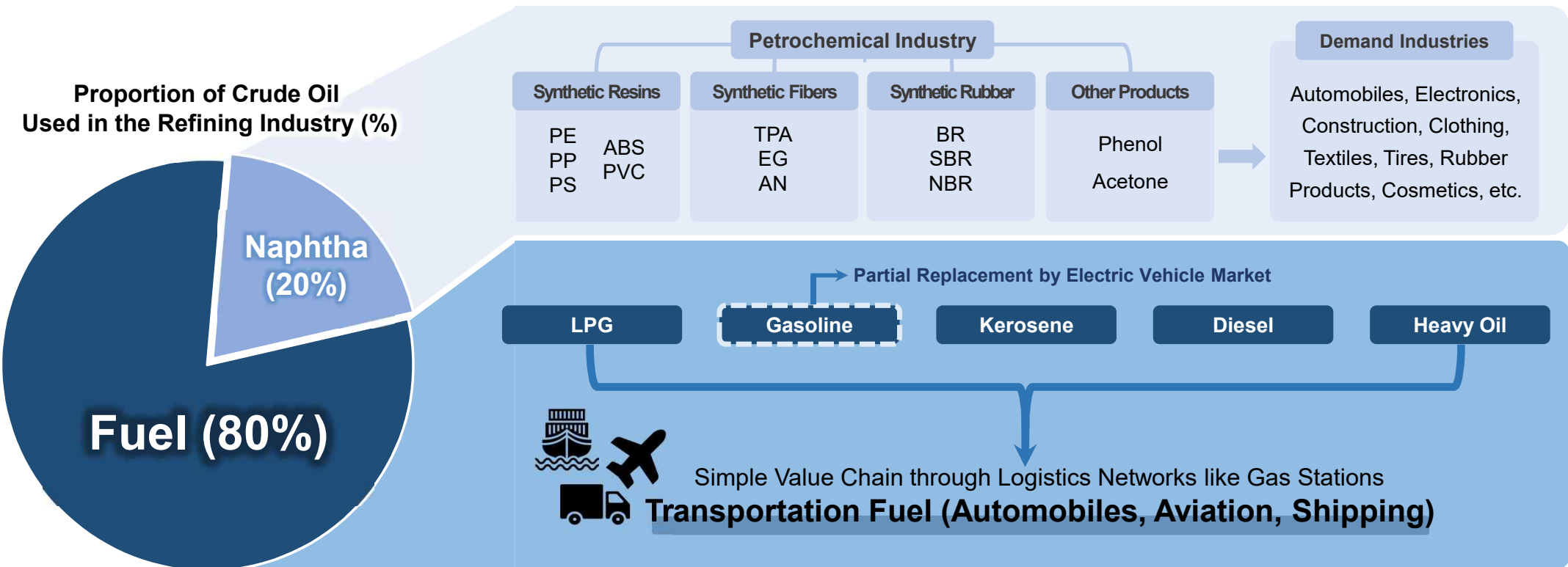
Natural gas/Coal:
Electricity

Oil: Transport

Value Chain of Chemical Industry (From Refinery to Consumer Products)

Carbon Neutrality and Biorefinery

Energy for Transportation & Raw Materials for Chemical Industry = **Mostly Oil !**

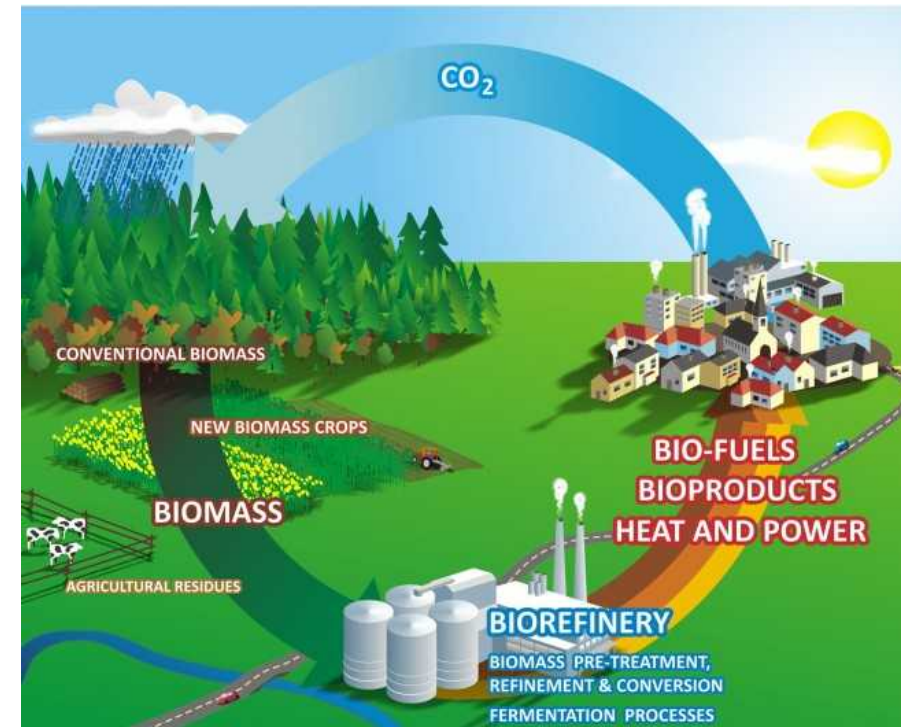
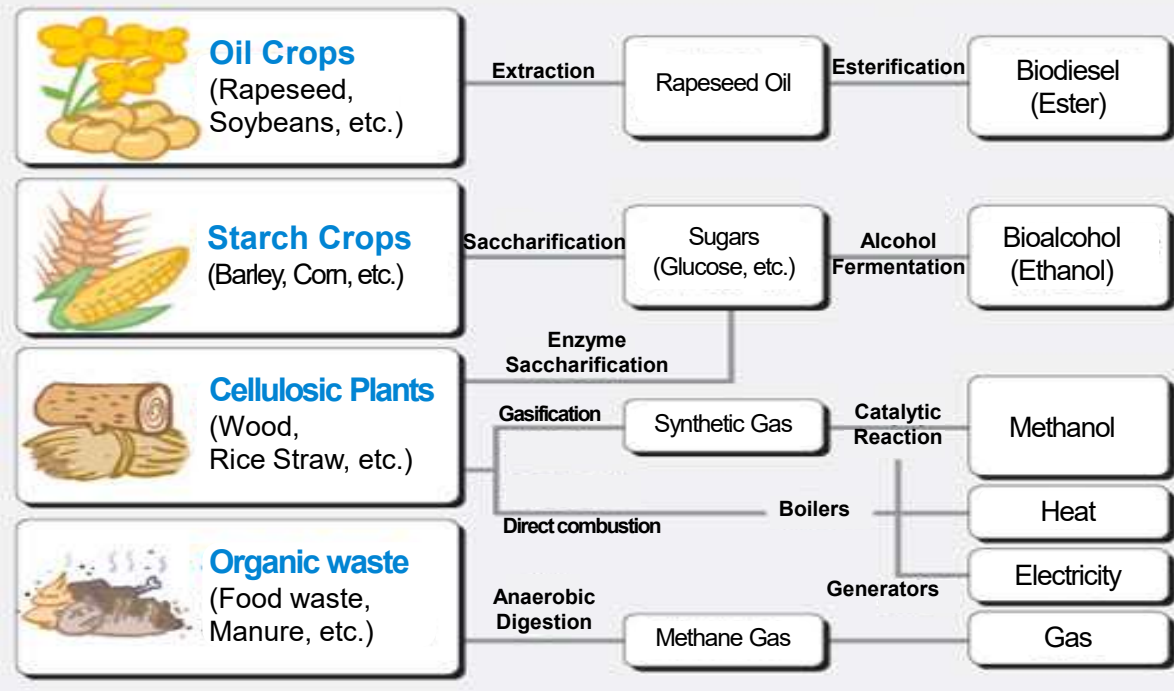


Alternative to Fossil Fuels, Biomass

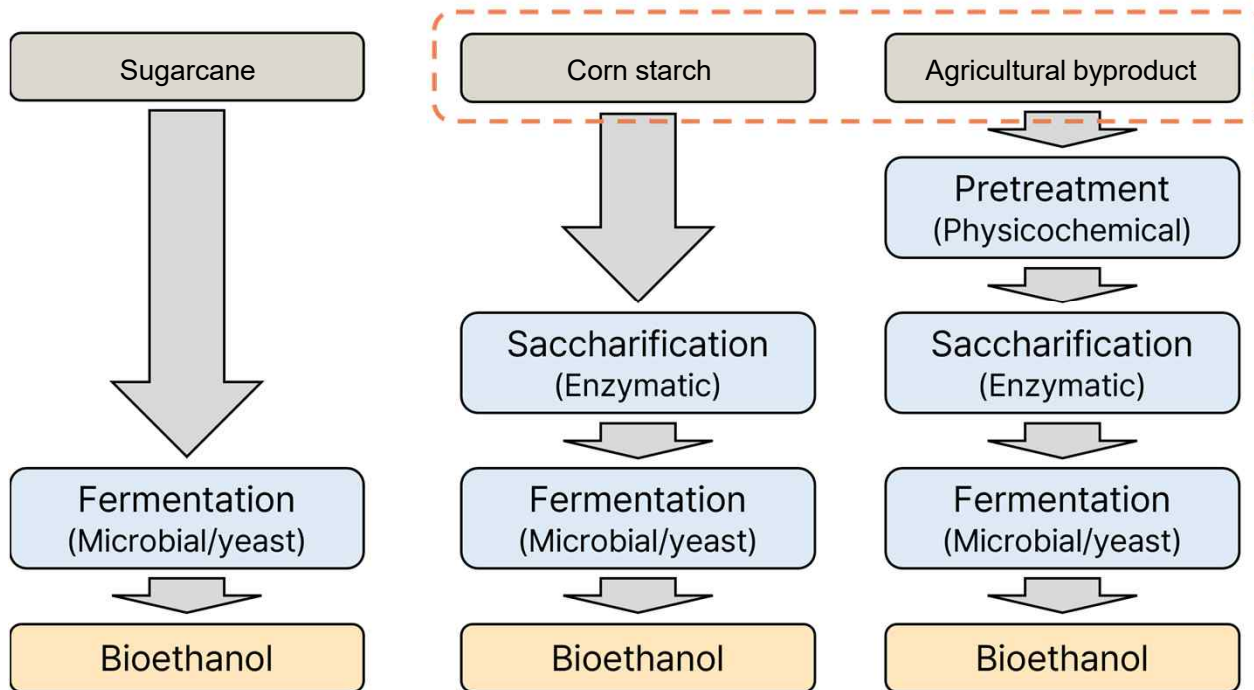
Carbon Neutrality and Biorefinery

- **Fossil fuel:** Hydrocarbon (C, H)
- **Biomass:** Sugar – C, H, O; Fat – C, H, O; Protein – C, H, O, N, S

Principles of Various Bioenergy Conversion



How About Non-Edible Biomass?



Problems of Agricultural Biomass

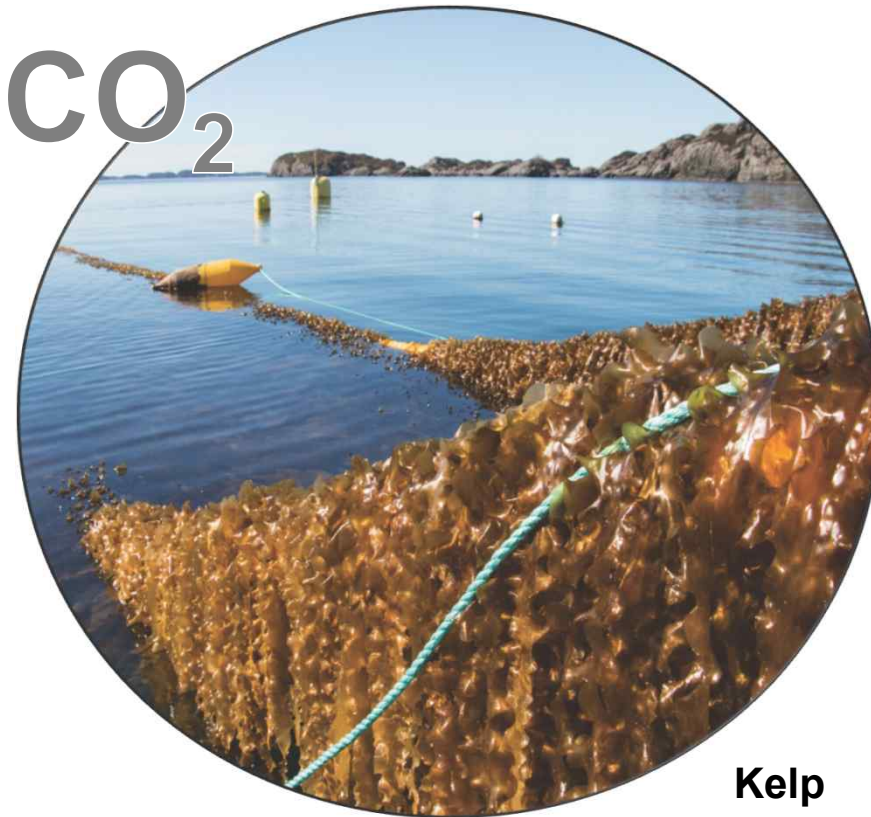
- Expensive processing costs due to intensive physicochemical pretreatment
- High content of non-saccharides substances such as lignin and gypsum
- Difficulty in managing raw material quality due to the use of agricultural or forestry by-products
- Need to secure new arable land for dedicated energy crops

Brown Macroalgae Biorefinery

Raw Materials for the Next Generation Biochemical Industry: Seaweed

Brown Macroalgae Biorefinery

Advantages of seaweed (brown algae such as kelp) as a raw material



No Land required

- Only 5% of the ocean's area is currently used
- There is no restriction on the space for seaweed farming

No Freshwater required

- Salt-containing seawater can be used immediately in seaweed farming

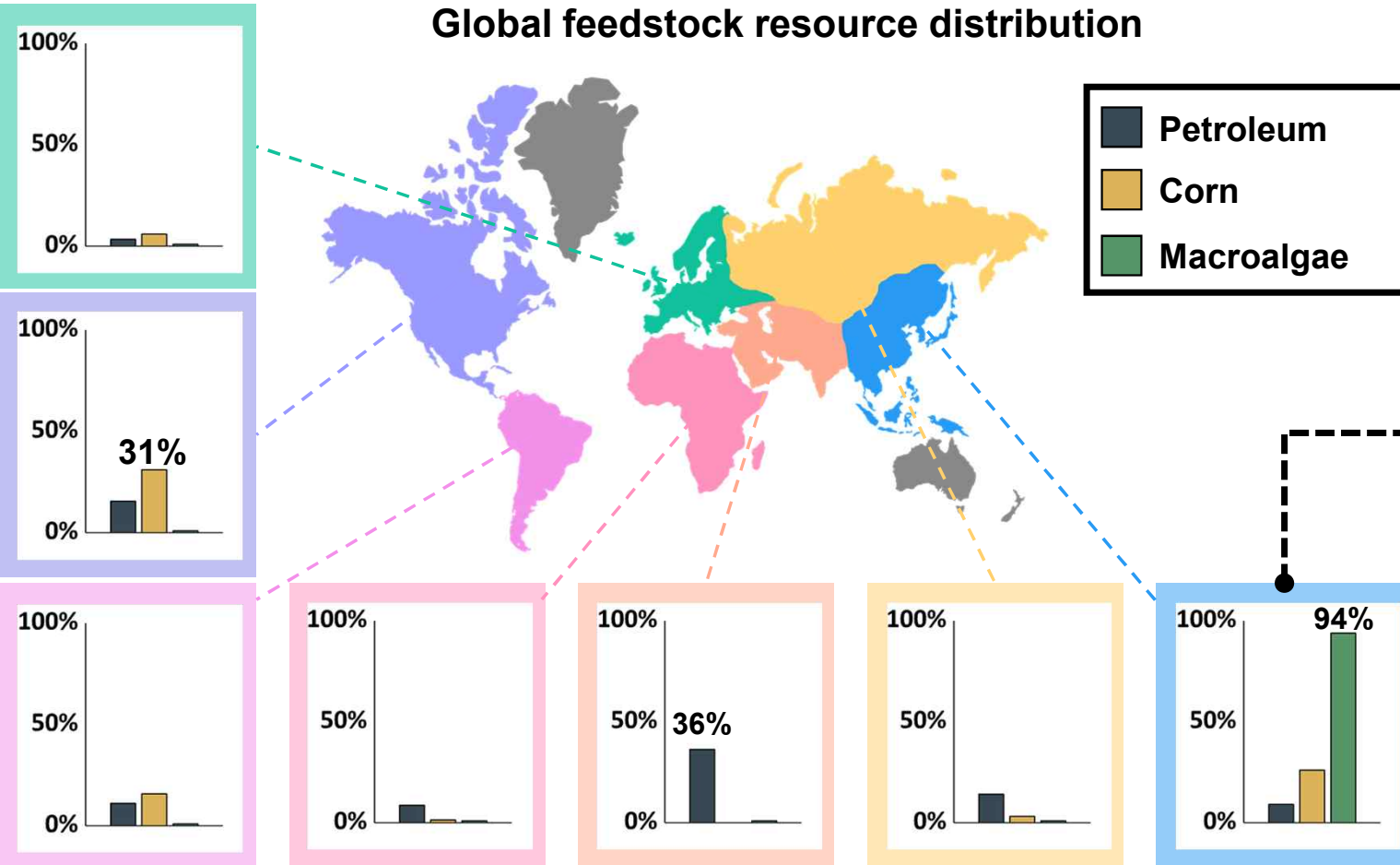
No Fertilizer required

- No fertilizer use required, because it absorbs inorganic nutrients from seawater and performs photosynthesis using carbon dioxide
- It has fast growth rate and high carbon dioxide absorption compared to terrestrial plants

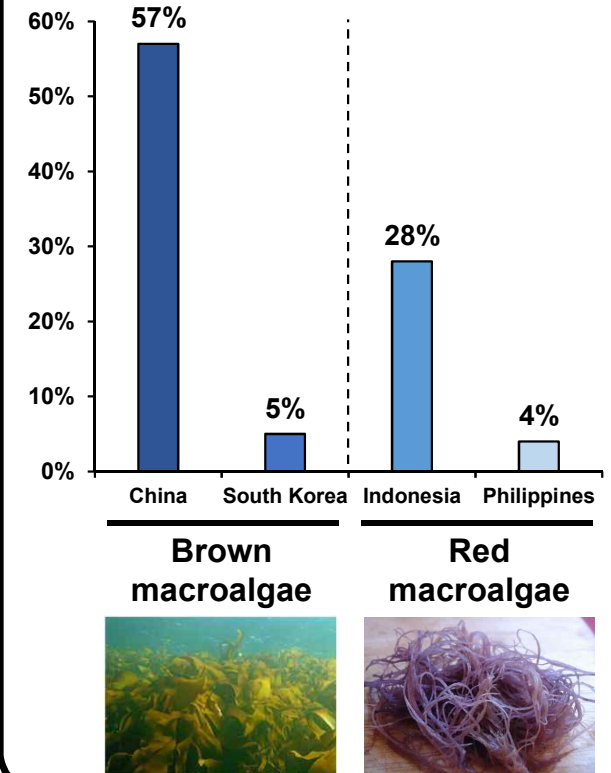
Feedstock Production by Regions

Brown Macroalgae Biorefinery

Global feedstock resource distribution



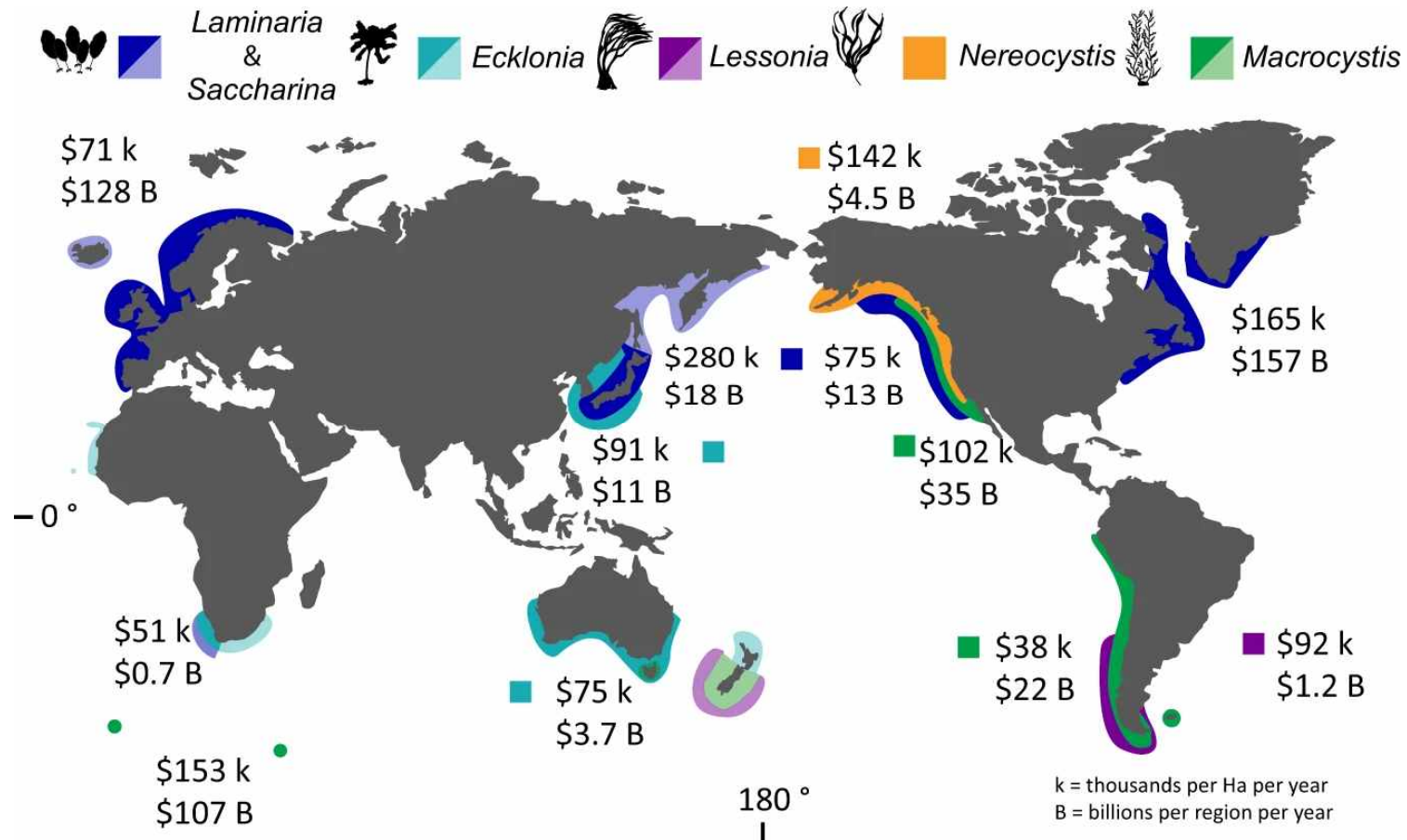
Global macroalgae production and contribution



Big Potential of Macroalgae for Production Expansion by Aquaculture

Brown Macroalgae Biorefinery

Global marine kelp forest



Big Potential of Macroalgae for Production Expansion by Aquaculture

Brown Macroalgae Biorefinery

South Korea's competitiveness in large-scale seaweed farming industry

Seaweed farm of Wando county



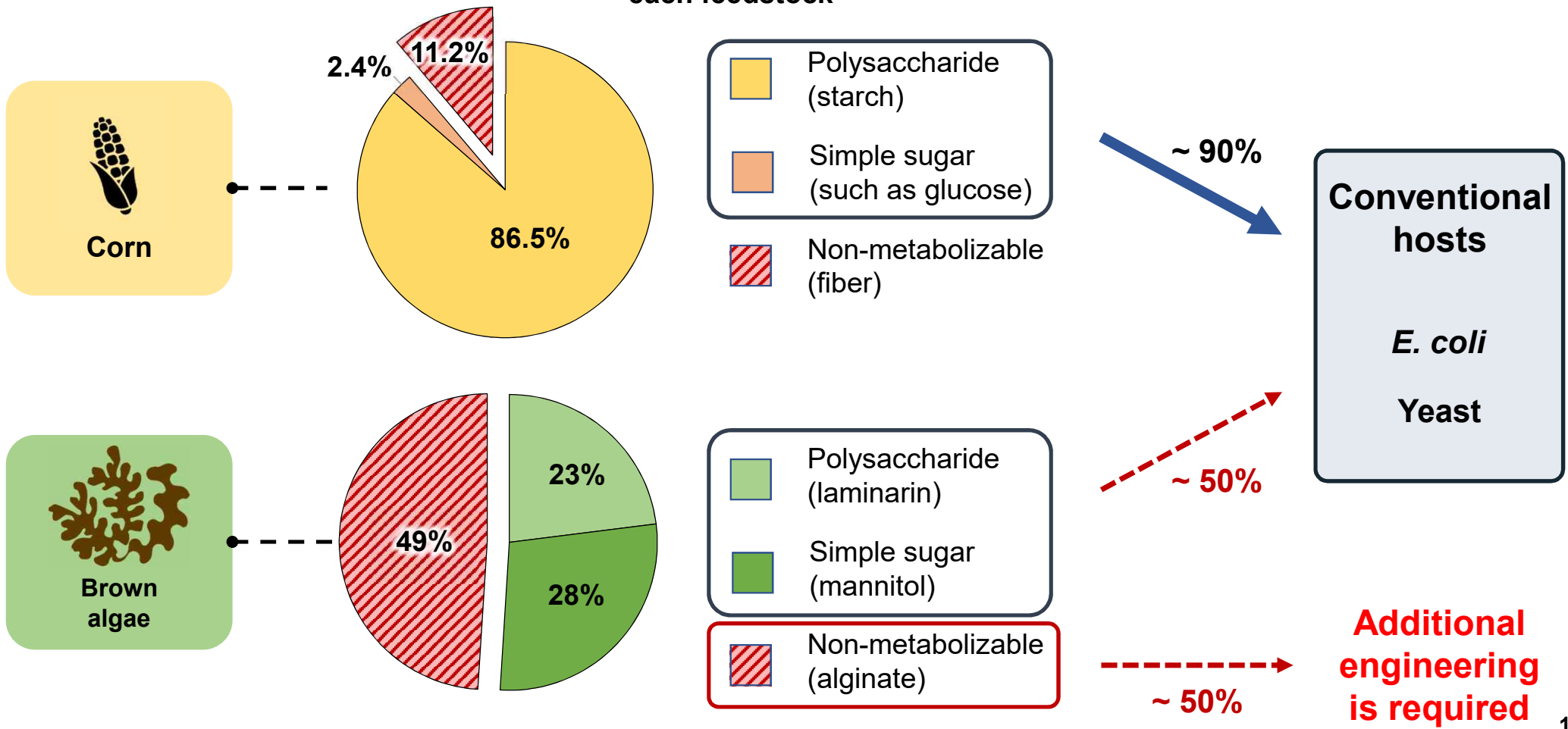
- Brown algae productivity per unit area: **60,000 tons/10 km²** (based on dry weight)
- South Korea's Aquacultureable Marine Area: Approximately **220,000 km²**
- South Korea's maximum annual production of brown algae: approximately **1.2 billion tons** (600 million tons per sugar)
- **10 billion tons** of sugar will be needed if the world's crude oil production is replaced by sugar
- **6% of the maximum global demand can be produced** in the aquaculture area of South Korea

Brown Algae Cannot Be Digested!!

– Low Glucose Content, High Non-metabolizable Sugars

Brown Macroalgae Biorefinery

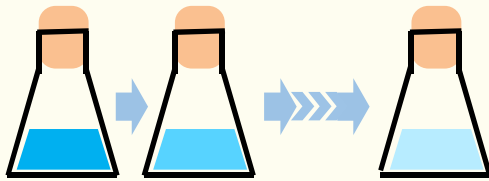
Carbohydrate composition of each feedstock



Alternative approach: Isolate a Novel Organism and Develop Genetic Tools

Brown Macroalgae Biorefinery

Enrichment of strains
directly metabolizing
brown macroalgae sugar

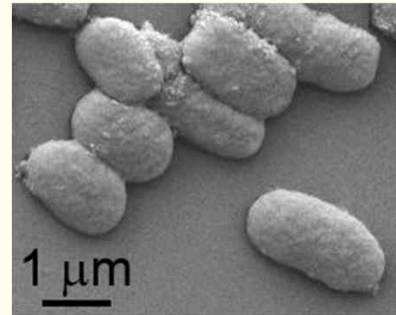


Seed preparation



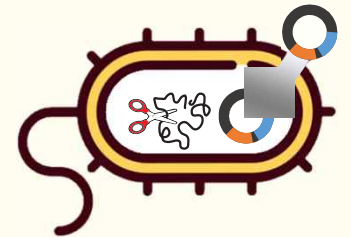
Seaweed sludge

Isolation of
a novel microorganism



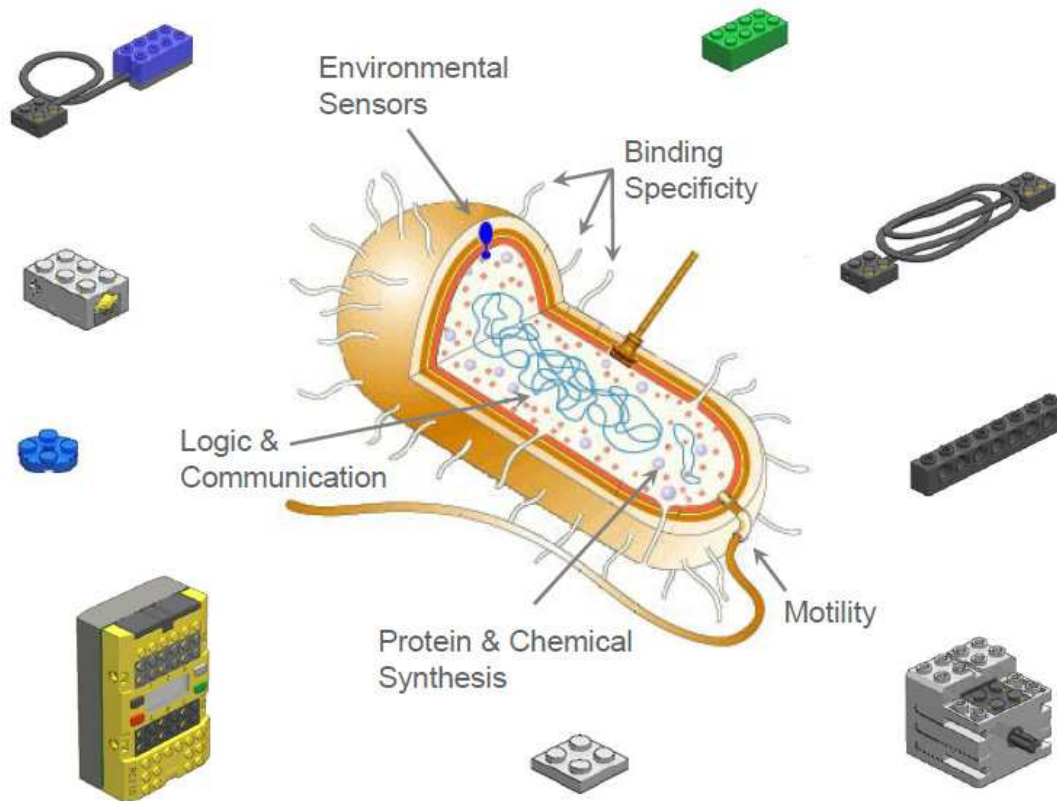
Vibrio sp. dhg

Development of
synthetic biology toolkits



Synthetic Biology to Design Life: Assembling Desired Microorganisms Like a Machine

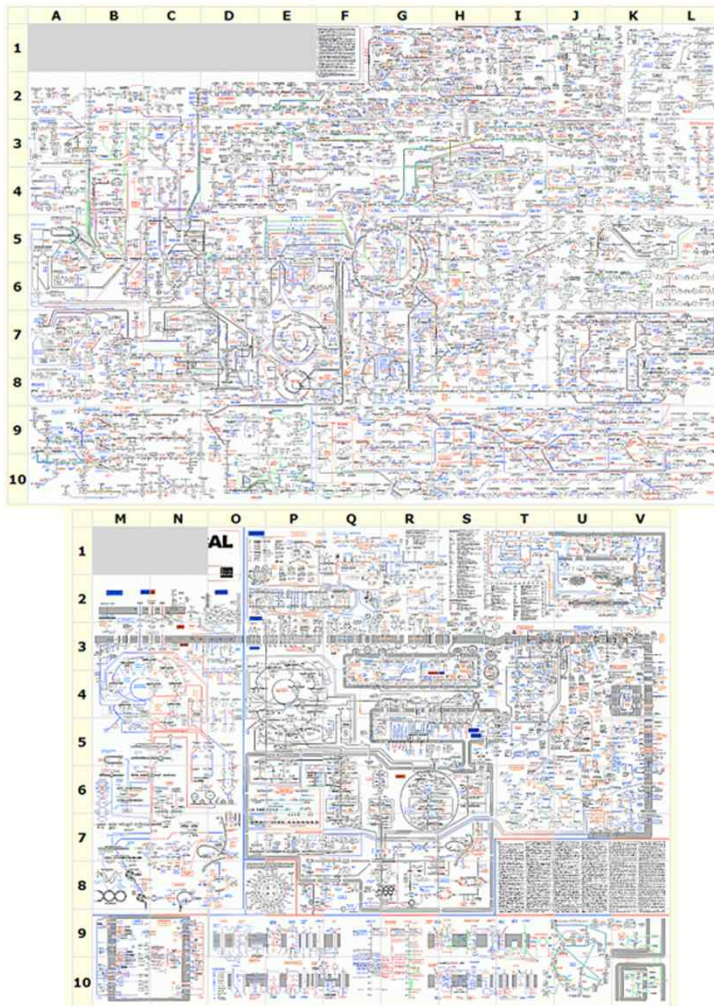
Brown Macroalgae Biorefinery



The key is genetic design and editing tools!!

- New tools for genetic design **optimized to the type of microorganism** are needed
- **Genome engineering toolkits** are also needed.
- **Genome sequencing and prediction of the function of microbial components**

Cellular metabolism is a combination of thousands of enzymatic reactions



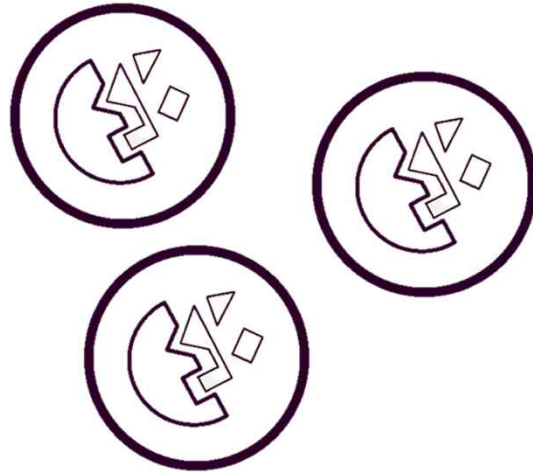
- Cellular physiology (performance of microbes) is determined by metabolism
- Metabolism is composed by thousands of enzymes
- DNA is coding for quantity and quality of enzymes

DNA sequence designer to predict quantity and quality of enzymes: assisted by AI

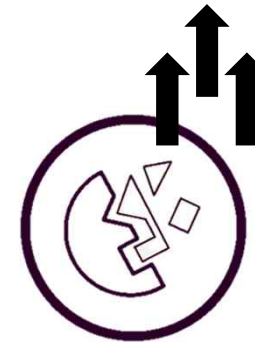


SCANEER

Our AI-assisted tools



and



Manipulating enzyme number

Promoter strength, 5' UTR sequence, plasmid copy number regulation

Manipulating enzyme specific activity

Heterologous expression of host gene

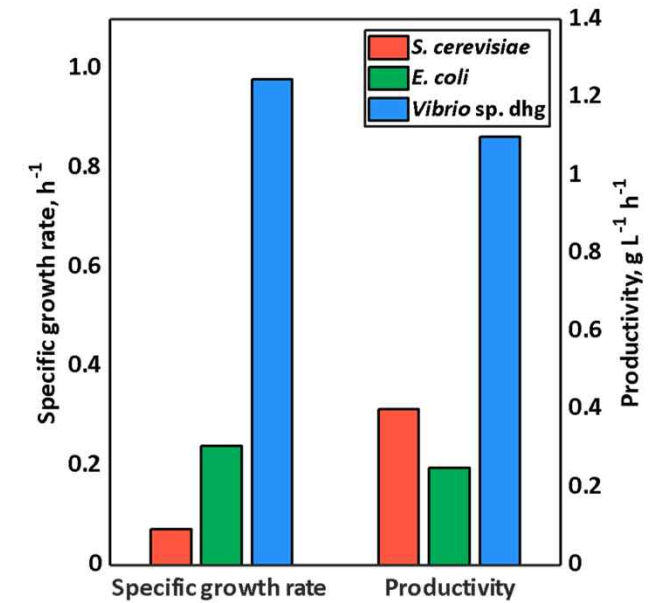
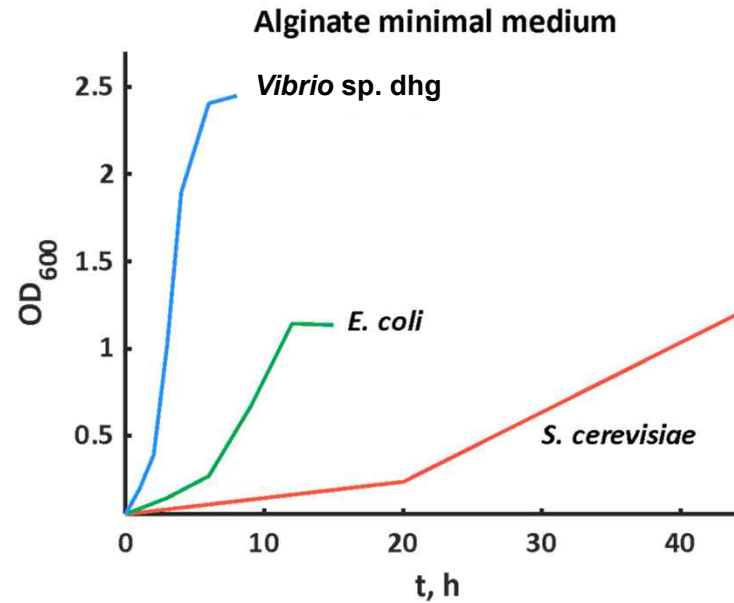
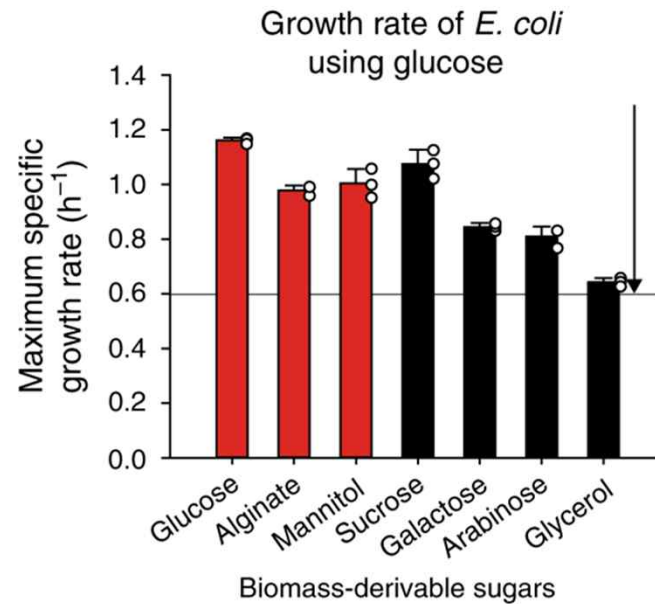
Our Breakthrough Technology:

Direct Conversion of Brown Algae and Engineering Technology (World's Best Performance !!!)

Brown Macroalgae Biorefinery

nature communications

- High growth rate and sugar consumption rate (~10 min of doubling time in rich medium)
- Establishment of synthetic biology tool
- Production of value-added chemicals by engineering the microorganism



Macroalgae Biorefinery Research Center (MBRC) of KOREA

Brown Macroalgae Biorefinery



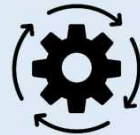
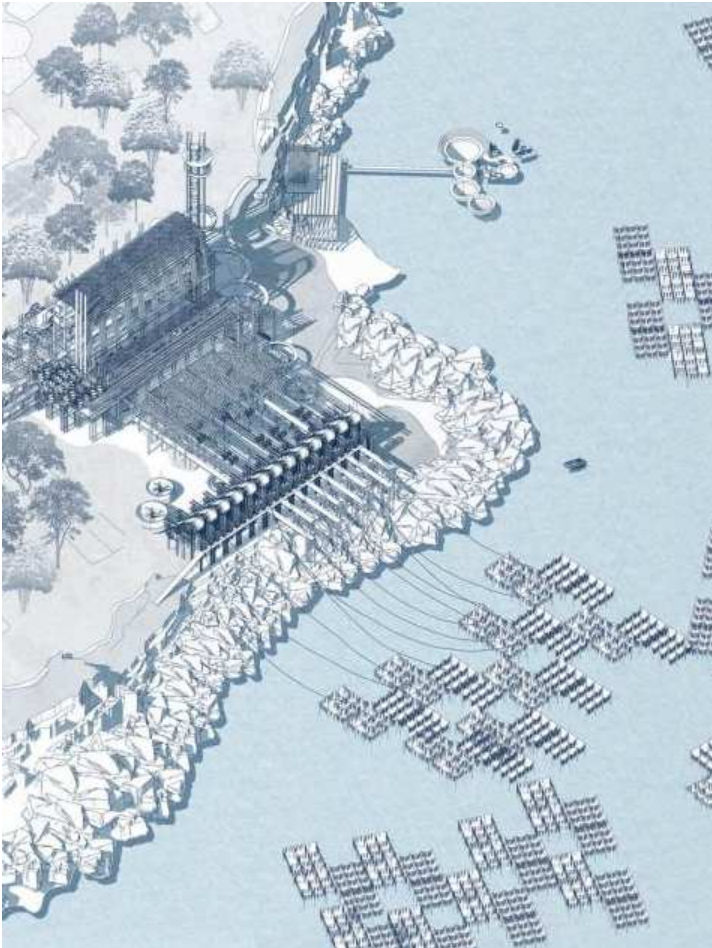
- 5-year research program (**total \$ 95,000**, 2022 - 2026) supported by Ministry of Oceans and Fisheries of KOREA
- Aiming to develop the **pilot-scale bioprocess for the production of 3-HP, itaconate, or lactate** utilizing **brown macroalgae as feedstock**

What's Next ?



Expanding the Supply of Seaweed Biomass: Advancing Seaweed Cultivation with Industry 4.0

What's Next ?



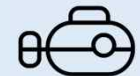
Development of an Integrated Seaweed Culture System

- Technology for Automating the Entire Process from Aquaculture to Harvesting



Development of Computational Models for Aquaculture Technology Development

- Surface Currents Modeling Based on Weather and Seasonal Changes, etc.



Development of Marine Monitoring Technology

- Underwater Environment and Ecological Monitoring



Development of Seaweed Improvement Technology

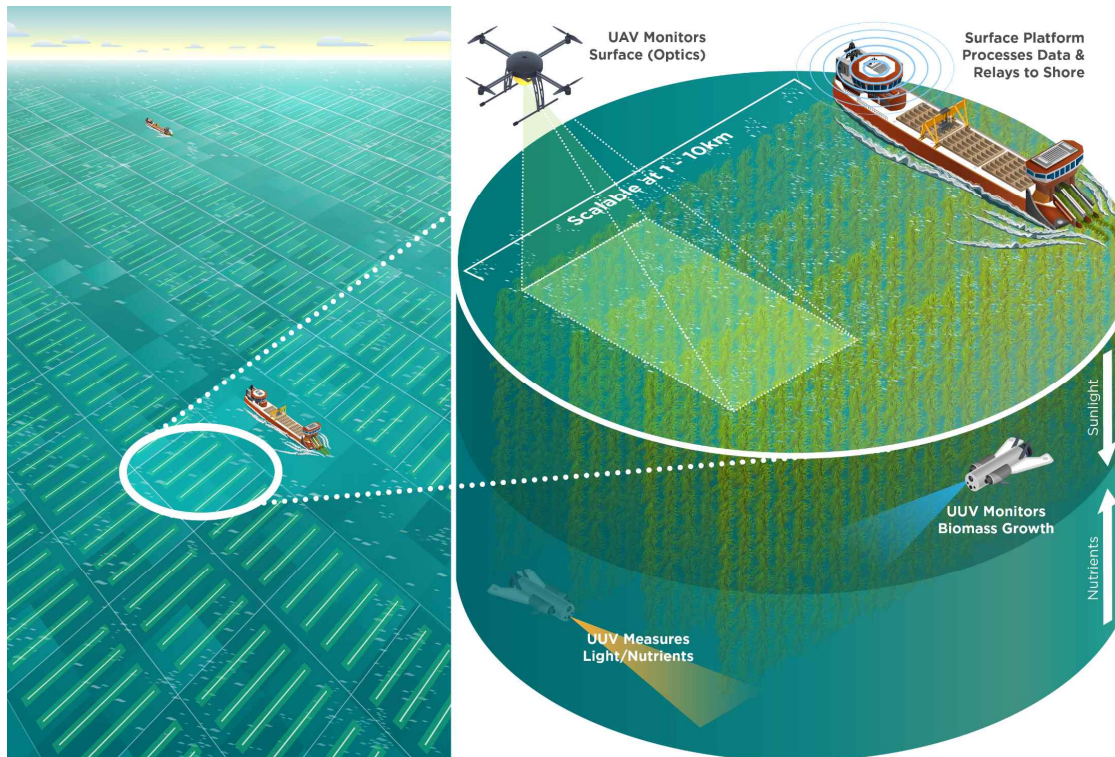
- Research on Foundational Technologies for Breeding and Genetic Improvement of Seaweed for Raw Materials

Expanding the Supply of Seaweed Biomass: Advancing Seaweed Cultivation with Industry 4.0

What's Next ?

Research and development programs in advanced countries for mass cultivation and resource utilization of seaweed

U.S. MARINER Program (\$62 million, started in 2016)



Technology Development Categories

- 1 • Cultivation & Harvest Systems
- 2 • Numerical Modeling Tools
- 3 • Remote Sensing & Monitoring Capabilities
- 4 • Advanced Breeding & Genomics
- 5 • Ecosystem Services & Nitrogen Extraction
- 6 • Seaweed Conversion
- 7 • Marine Spatial Planning & Lifecycle Assessment

Initiation of International Cooperation for Seaweed-based Chemical Industry

What's Next ?

Korea-U.S. Joint Development of Offshore Seaweed Aquaculture Technology

KIMST & ARPA-E MOU Signing Ceremony

해양수산과학기술진흥원과 ARPA-E 업무협약 체결식

Jan. 19 (Fri), 2024 | Ministry of Oceans and Fisheries



- ARPA-E (US) and KIMST (Korea) signed a MOU to strengthen cooperation in marine and fisheries research to develop automated offshore cultivation technology for brown algae to use it as a marine biochemical resource
 - ✓ Starting in 2025, approximately \$40 million from the U.S. side and \$29 million from the Korean side will be invested over about 5 years
 - ✓ The goal is to develop technology for mass supply of seaweed with a production cost of less than \$80 per ton of dry weight
→ aiming for an oil price range of \$50-100 per barrel

Expanding the Supply of Seaweed Biomass: Advancing Seaweed Cultivation with Industry 4.0

What's Next ?

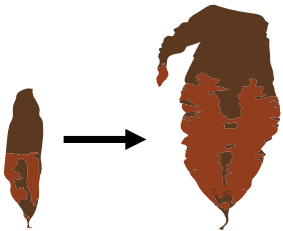
Fostering global companies at the forefront of seaweed-based new industries

Seaweed engineering

Seaweed cultivation

Seaweed supply network

Production of biochemicals



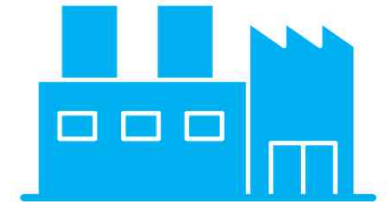
- Breeding of seaweed
- Enhancement in heat resistance, photosynthesis, carbohydrate contents
- Precise genome editing technologies



- Mass cultivation of seaweed
- Non-labor-intensive production
- Automated technology for site selection, monitoring, and seeding of seaweed cultivation



- Seaweed resource management industry
- Technology for lower costs and timely supply of raw material
- Establishment of supply chains and infrastructure



- Integrated seaweed biochemical plants
- Production of various biochemical products
- Bioactive substance extraction and highly value-added chemical production from seaweed

Future Marine Biotech: Need for Global Companies and Workforce

South Korea's Potential in the Seaweed-based Biochemical Industry

World's Largest Seaweed Cultivation Area



World's Best Seaweed Cultivation Technology



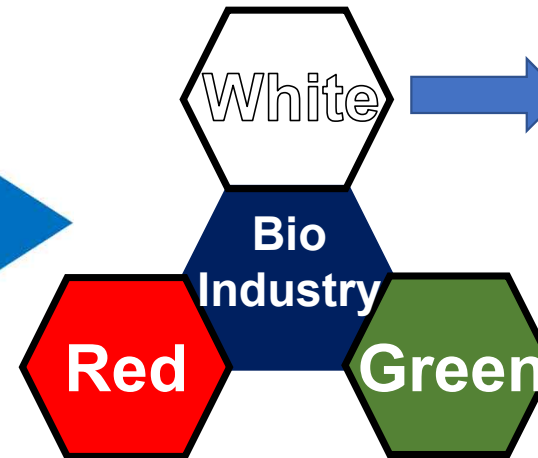
World's Best Industrial Infrastructure



World-Class Technology & Environment

What's Next ?

- Raw materials for biochemical industry (biodegradable plastics, enzyme materials, etc.)
- Biofuels (gasoline, aviation fuel, etc.)



CJ CheilJedang – Global Leading Biocompany (PHA producer)



GS-Caltex – Global bio-based chemical producer



- Bioactive substances
- Raw materials for pharmaceuticals / medical materials (sutures, etc.)

- Food additives, livestock feed
- Fertilizers for agriculture
- Biochar and syngas

K-Eco-friendly Marine Biochemical Complex

What's Next ?

Consolidated Bioprocessing

- Pre-treatment for fermentation
- Chemical production
- Purification of chemical products

Biochemical Industry

- Petrochemical alternatives
- Food additives and animal feeds
- Pharmaceuticals



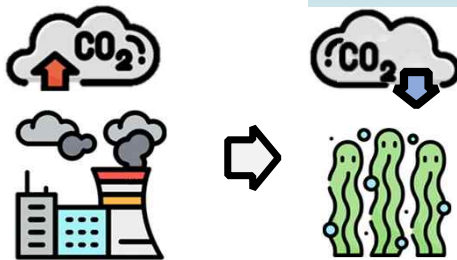
Seaweed Transportation

- Development of autonomous transport equipment
- Transportation of seaweed

Mass Seaweed Cultivation

- Cost-competitive raw materials through large-scale cultivation
- Marine environment monitoring

World's First K-Eco-Friendly Marine Biochemical Complex



CO₂ Reduction



Eco-friendly chemical
for environmental improvement



Increasing income
for marine industry
workers

Macroalgae Biorefinery Research Center (MBRC) of KOREA

■ The Jung Lab (Prof. Gyoo Yeol Jung)



■ Collaborators

- Prof. Sang Woo Seo, Seoul National University
- Prof. Hyun Gyu Lim, Inha University
- Prof. Sungho Jang, Incheon National University
- Prof. Jina Yang, Jeju National University
- Prof. Sung In Lim, Pukyong National University
- Prof. Jaekyoung Lee, Pukyong National University
- Prof. Chulhwan Park, Kwangwoon University
- Prof. Pyung Cheon Lee, Ajou University
- Prof. Bun Yeoul Lee, Ajou University
- Prof. Sunghoon Park, UNIST
- Prof. Jong Moon Park, POSTECH
- Dr. Kyusoon Shin, Noroo Holdings

■ Funded by Ministry of Oceans and Fisheries of KOREA

THANK YOU