Microbial Fuel Cell

- Microbes oxidise org. matter and electrons and protons are released.
- Electrons flow to the cathode through external circut producing electrical current.
- Protons flow through membrane to the cathode.
- O_2 (or any other electron acceptor) reacts with electrons and protons forming water.

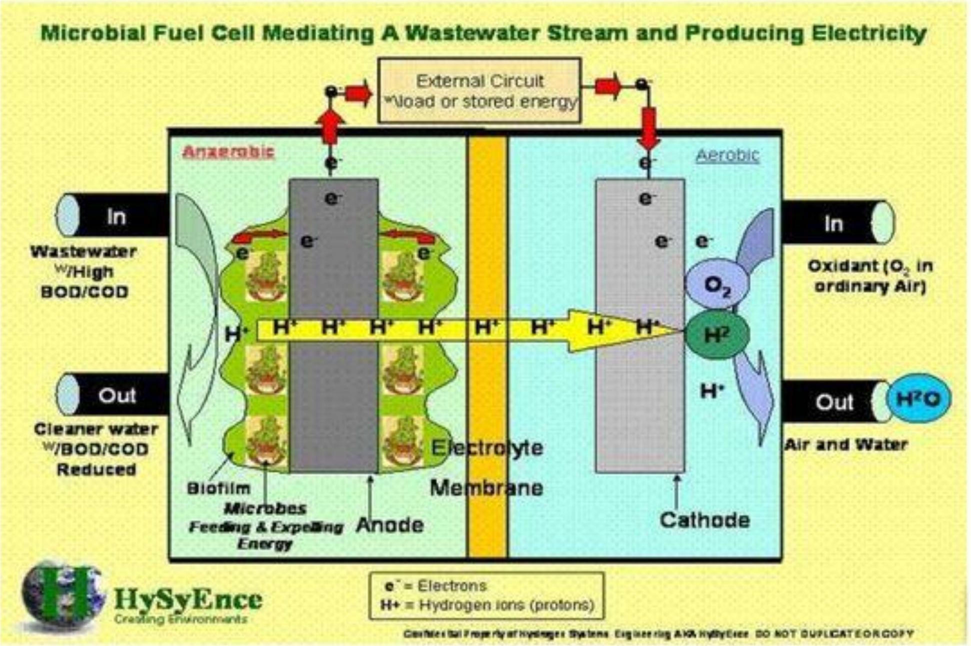
- Anode chamber is anaerobic and there should be an electron acceptor in cathode chamber.

Anode

$$CH_3COO^- + 2H_2O \rightarrow 2CO_2 + 7H^+ + 8e^-$$

Cathode

$$O_2 + 4\,e^- + 4H^+ \rightarrow 2H_2O$$

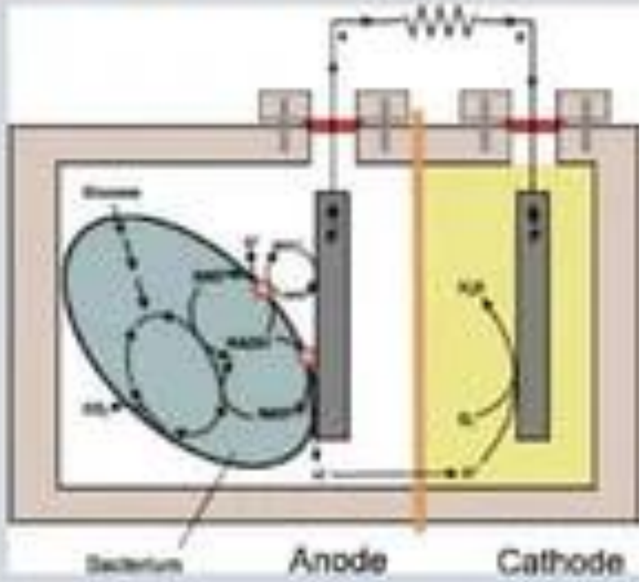


Components of MFC…

1. Anode chamber,
2. Cathode chamber,
3. membrane that seperates the anode and cathode chamber(like potassium nitrate base membrane or salt type membrane),
4. Electrodes(cu or al),
5. copper wire that joins electrodes,
6. waste water that contain organic materials.

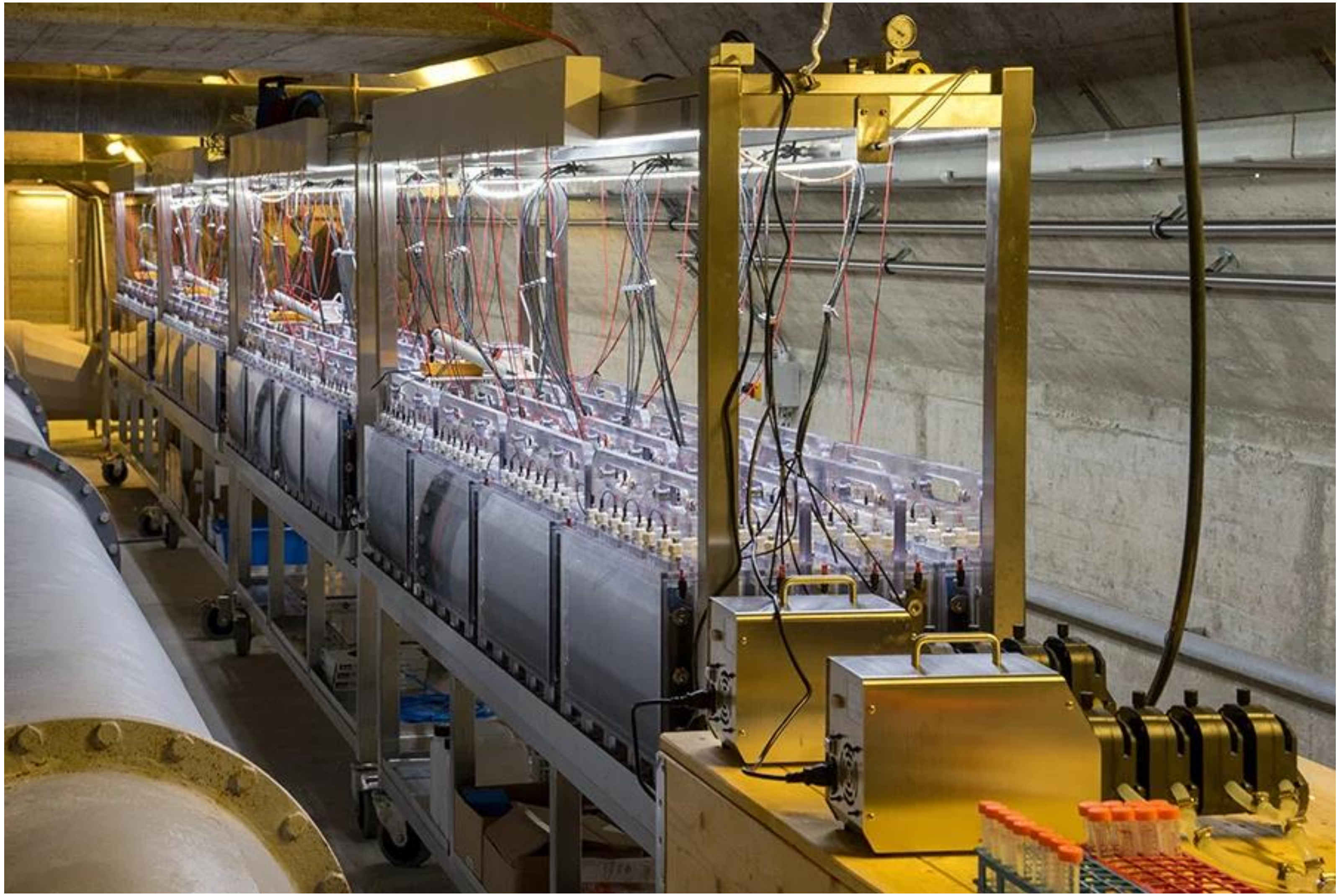
How Does It Work????

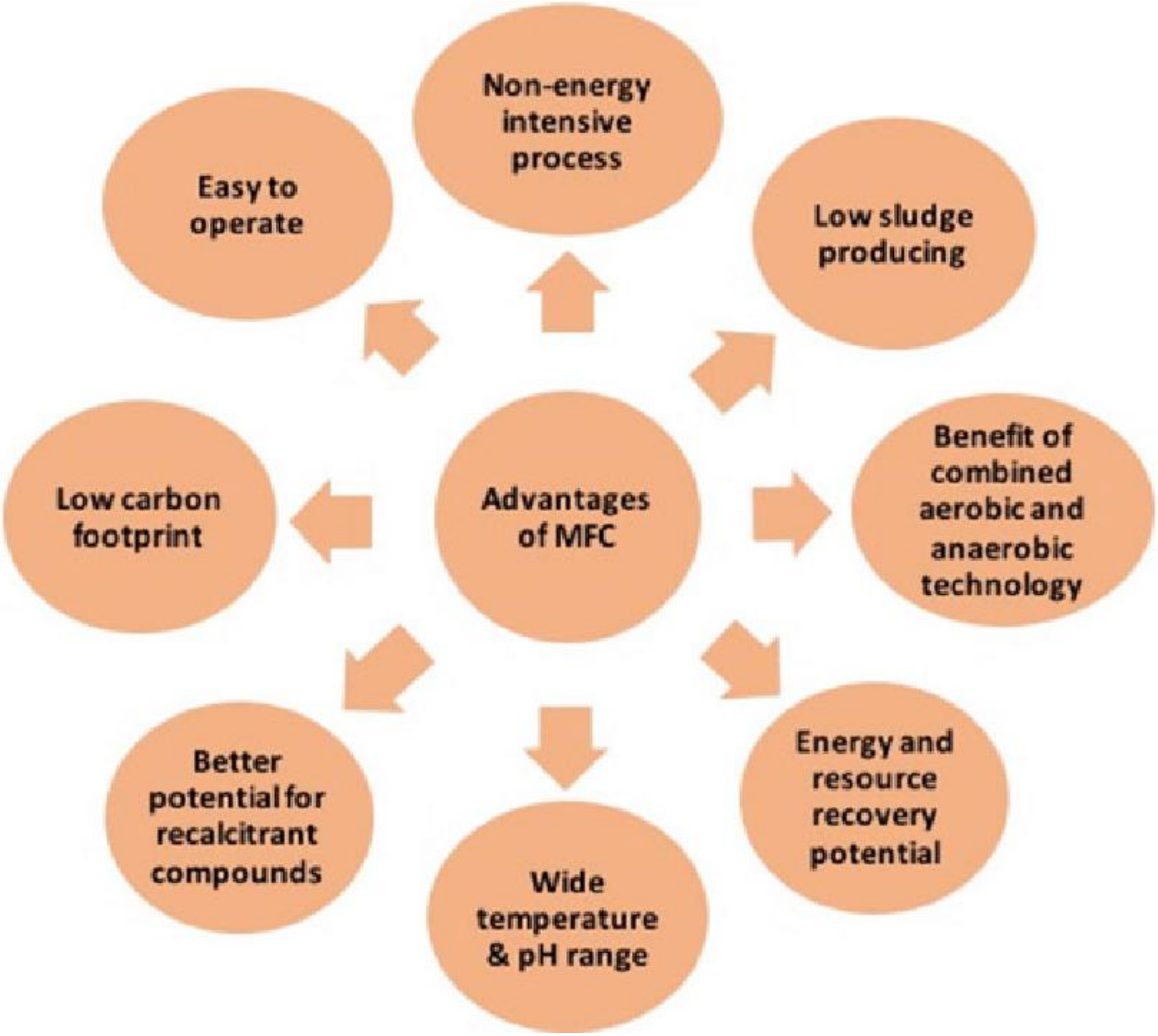
- Organic matter is oxidized by bacteria creating an electric potential and generating Co2, protons and electrons.
- Electrons are transferred to the cathode compartment through an external electric circuit, while protons are transferred to the cathode compartment through the membrane.
- Electrons and protons are consumed in the cathode compartment, combining with oxygen to form water.

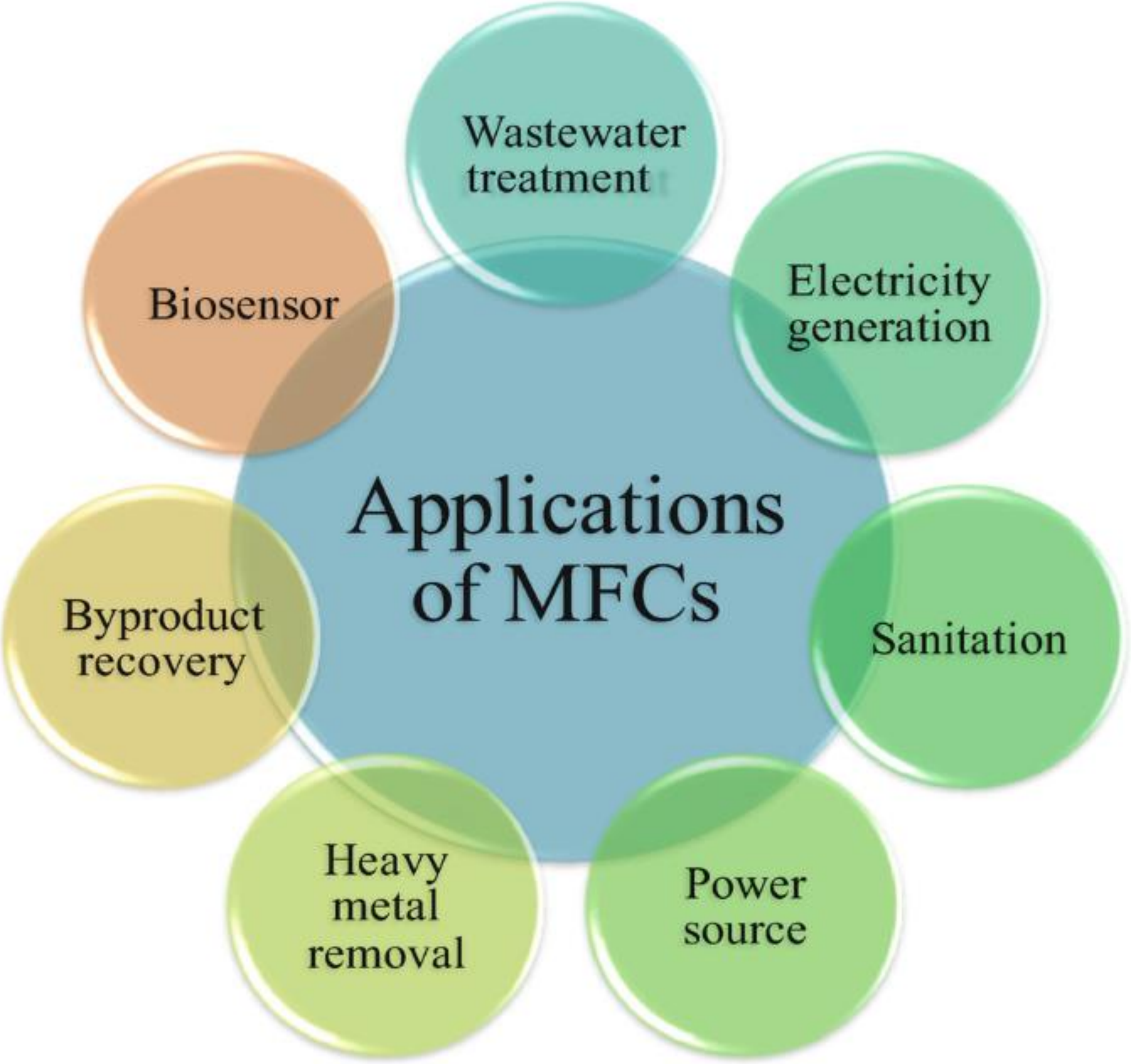


Anode reaction : $C_{12}H_{22}O_{11} + 13H_2O \dashrightarrow 12CO_2 + 48H^+ + 48e^-$

Cathode reaction : $4H^+ + O_2 + 4e^- \rightarrow 2H_2O$



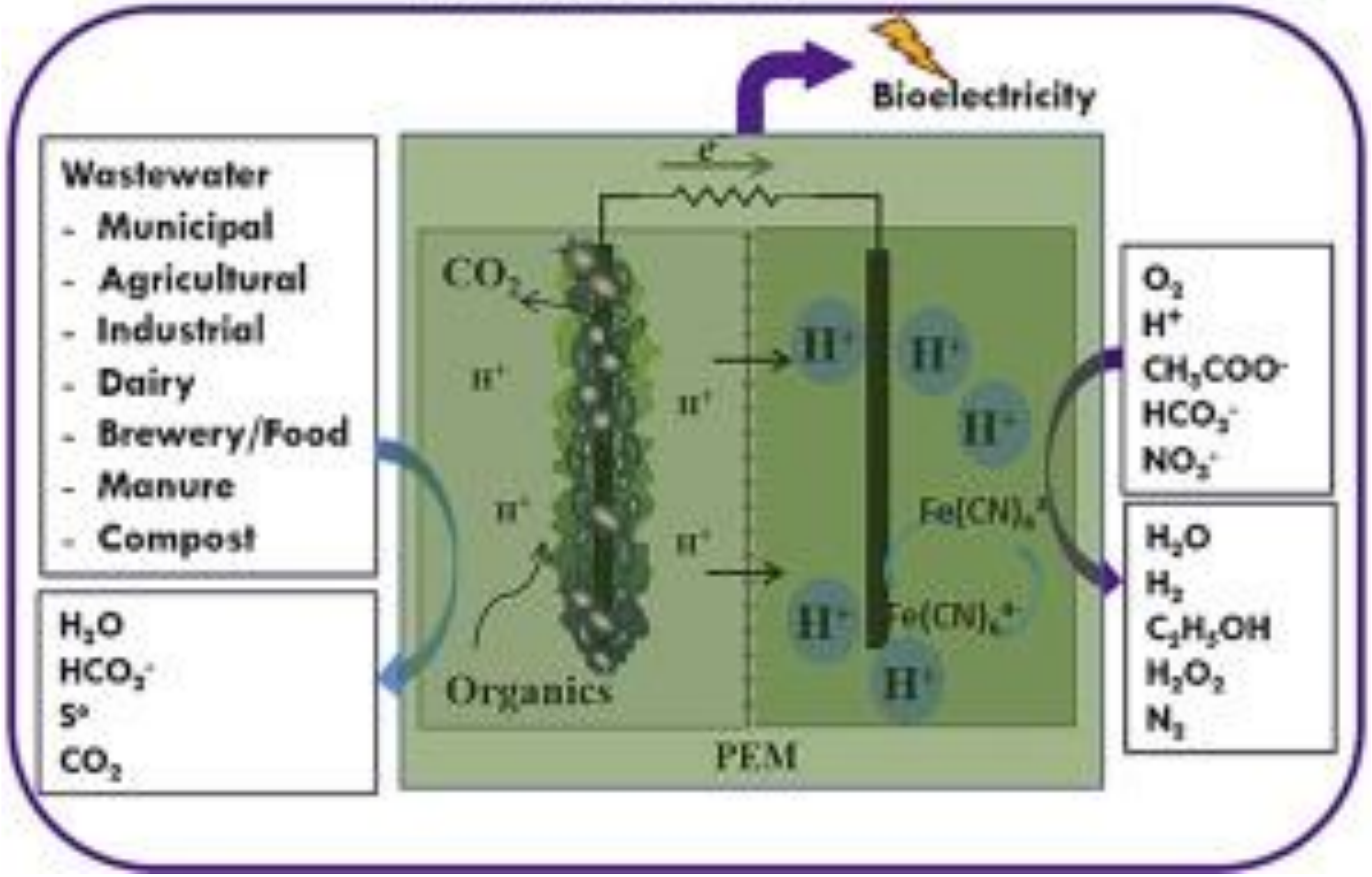

Non-energy intensive process
Easy to operate
Low sludge producing
Low carbon footprint
Advantages of MFC
Benefit of combined aerobic and anaerobic technology
Better potential for recalcitrant compounds
Wide temperature & pH range
Energy and resource recovery potential


Wastewater treatment
Electricity generation
Sanitation
Power source
Heavy metal removal
Byproduct recovery
Biosensor
Applications of MFCs

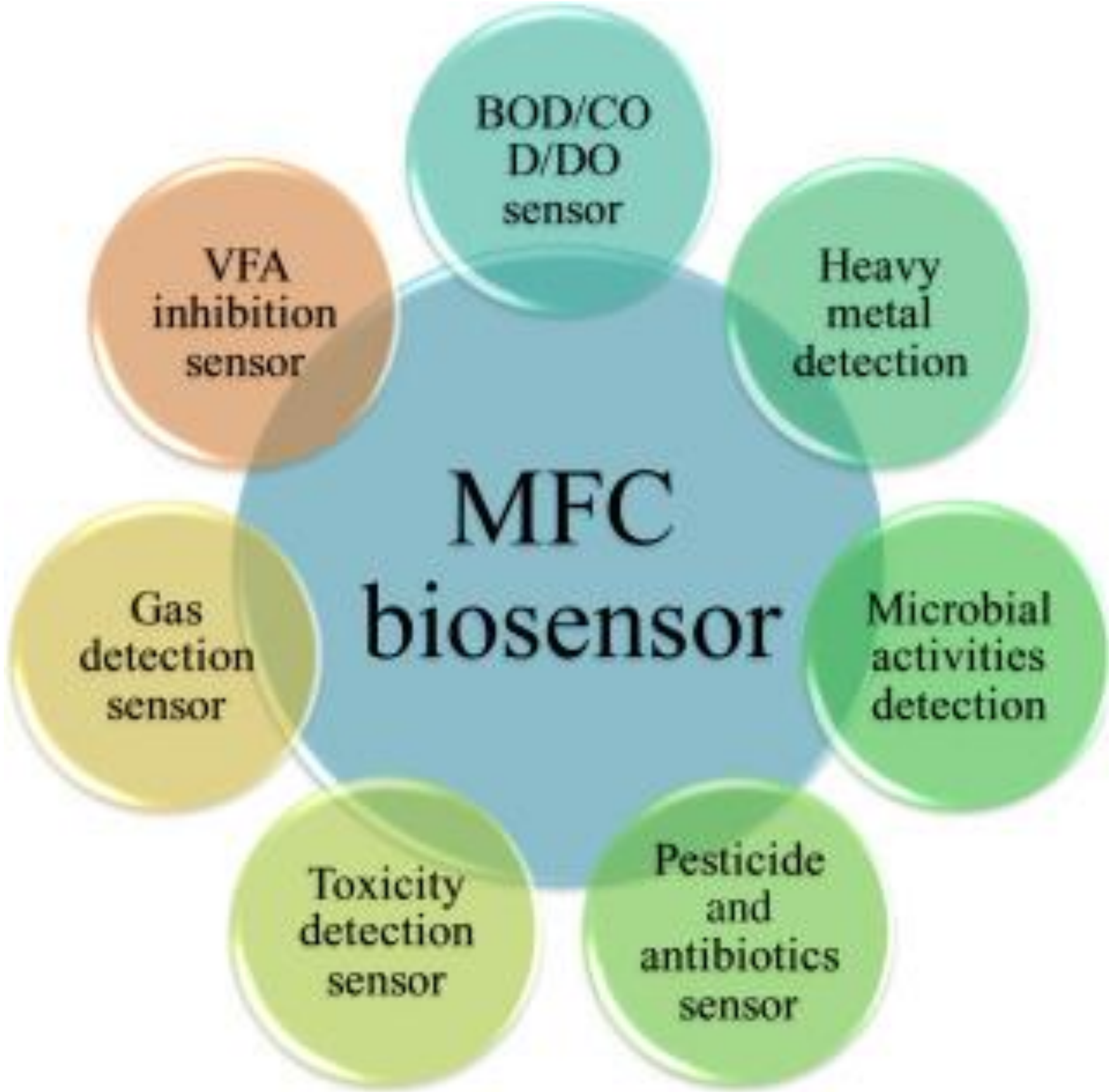
Applications of microbial fuel cell technology

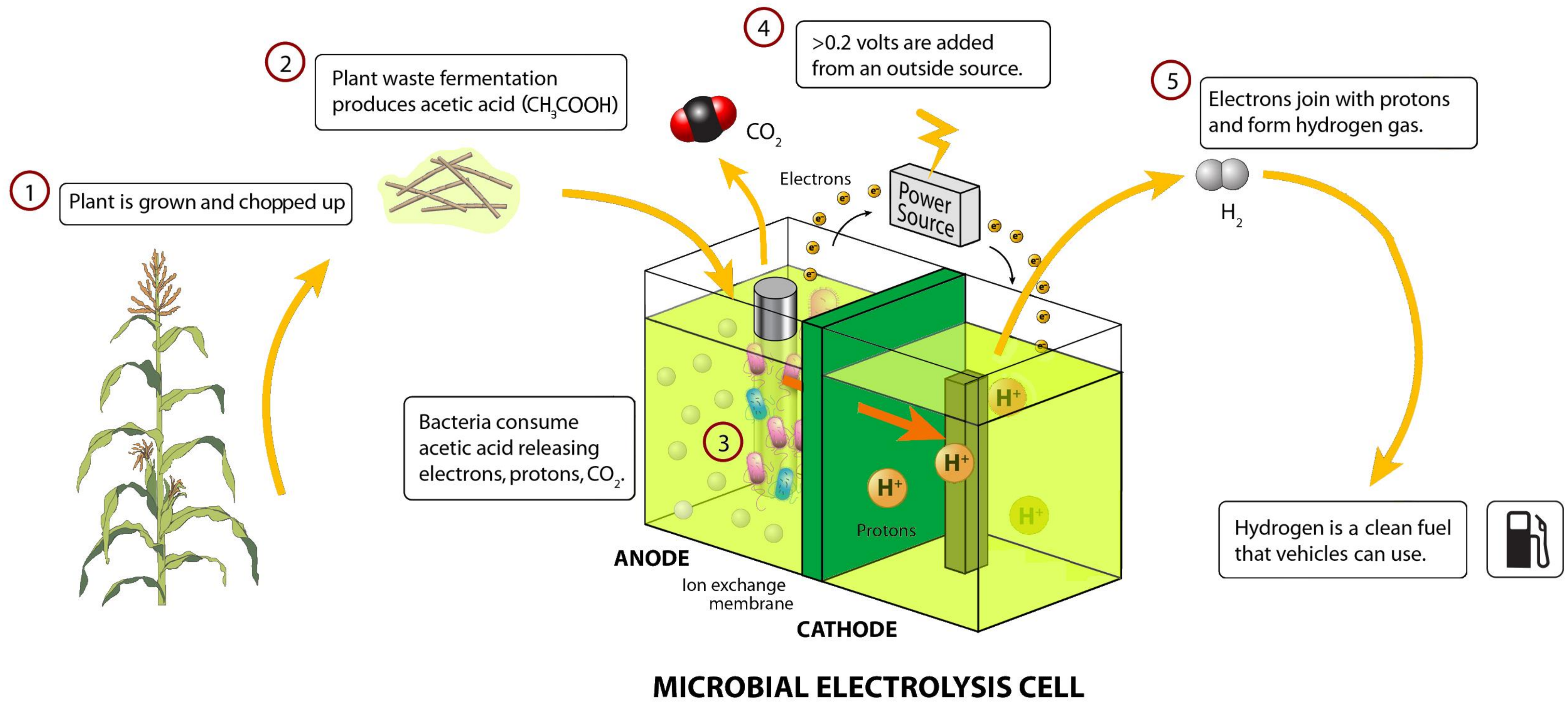
- **Wastewater treatment:** Micro-organisms can perform the dual duty of degrading effluents and generating power. MFCs are presently under serious consideration as devices to **produce electrical power** in the course of treatment of industrial, agricultural, and municipal wastewater. When **micro-organisms oxidize organic compounds present in waste water, electrons are released yielding a steady source of electrical current.** If power generation in these systems can be increased, MFCs may provide a new method to offset operating costs of waste water treatment plants, making advanced waste water treatment more affordable in both developing and industrialized nations. In addition, MFCs are also known to generate less excess sludge as compared to the aerobic treatment process.
- **Powering underwater monitoring devices:** Data on the natural environment can be helpful in understanding and modeling ecosystem responses, but sensors distributed in the natural environment require power for operation. **MFCs can possibly be used to power such devices, particularly in river and deep-water environments where it is difficult to routinely access the system to replace batteries**. Sediment fuel cells are being developed to **monitor environmental systems such as creeks, rivers, and oceans.** Power densities are low in sediment fuel cells because of both the low organic matter concentrations and their high intrinsic internal resistance. However, the low power density can be offset by energy storage systems that release data in bursts to central sensors.

Microbial Fuel Cells



- **Power supply to remote sensors:** With the development of **micro-electronics and related disciplines the power requirement for electronic devices has drastically reduced.** Typically, batteries are used to power chemical sensors and telemetry systems, but in some applications **replacing batteries on a regular basis can be costly, time-consuming, and impractical**. A possible solution to this problem is to **use self-renewable power supplies, such as MFCs, which can operate for a long time using local resources**. Extensive research toward developing reliable MFCs to this effect, is **focused mostly on selecting suitable organic and inorganic substances that could be used as sources of energy.**
- **BOD sensing:** Another potential application of the MFC technology is to **use it as a sensor for pollutant analysis and in situ process monitoring and control**. Biological Oxygen Demand (BOD) is the amount of dissolved oxygen required to meet the metabolic needs of aerobic organisms in water rich in organic matter, such as sewage. The proportional correlation between the coulombic yield of MFCs and the concentration of assimilable organic contaminants in wastewater make MFCs possible usable as BOD sensors. **An MFC-type BOD sensor can be kept operational for over 5 years without extra maintenance, far longer in service life span than other types of BOD sensors reported in the literature**.
- **Hydrogen production:** Hydrogen production by modified MFCs operating on organic waste may be an interesting alternative. In such devices, **anaerobic conditions are maintained in the cathode chamber and additional voltage of around 0.25 V is applied to the cathode**. **Under such conditions, protons are reduced to hydrogen on the cathode. Such modified MFCs are termed bio-electrochemically assisted microbial reactors (BEAMR)**


BOD/CO
D/DO
sensor
VFA
inhibition
sensor
Heavy
metal
detection
MFC
biosensor
Gas
detection
sensor
Microbial
activities
detection
Toxicity
detection
sensor
Pesticide
and
antibiotics
sensor



A microbial electrolysis cell (MEC) is a technology related to Microbial fuel cells (MFC). Whilst MFCs produce an electric current from the microbial decomposition of organic compounds, MECs partially reverse the process to generate hydrogen or methane from organic material by applying an electric current.

Oleaginous microorganisms

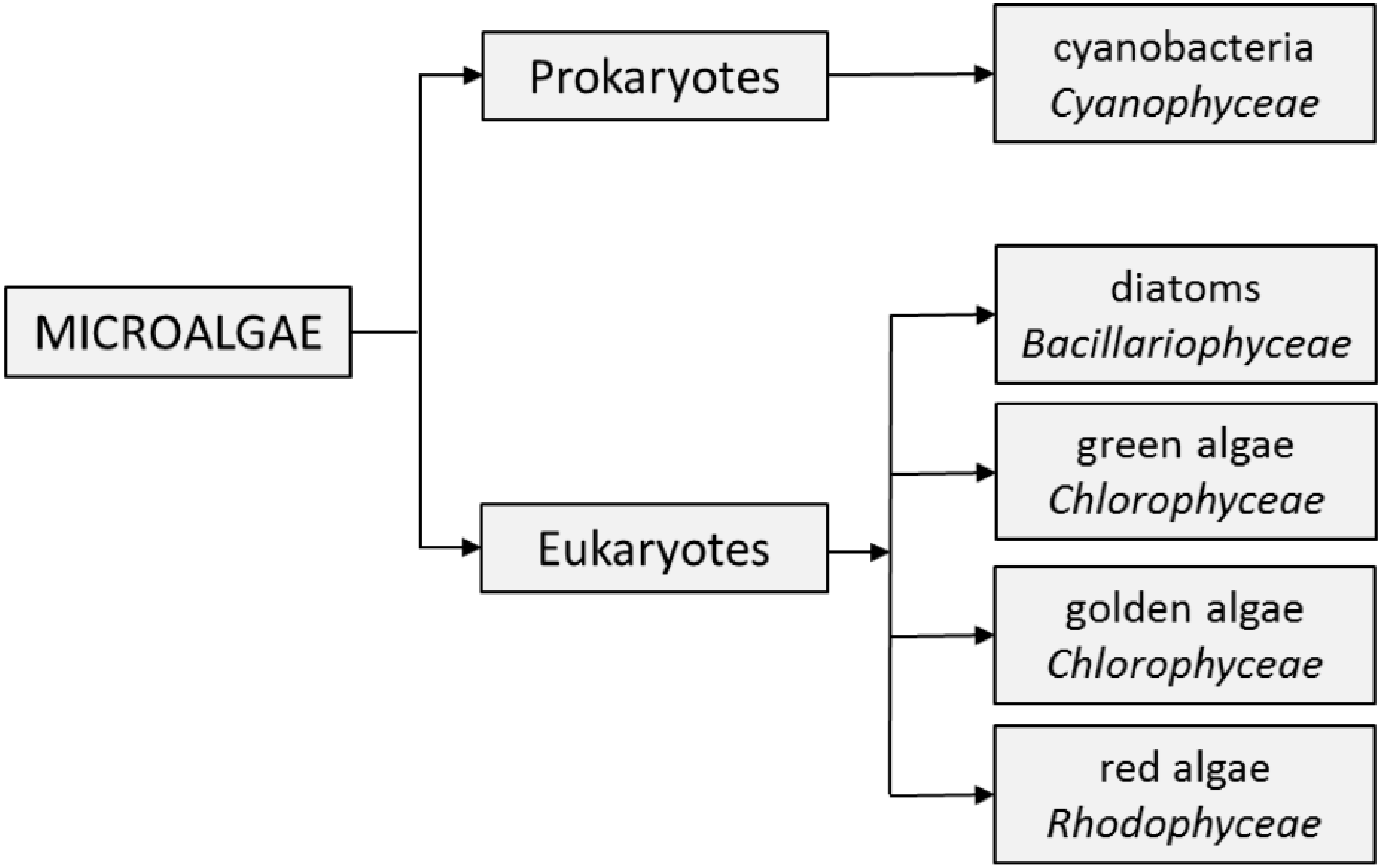
- Oleaginous microorganisms are species that are able to store oil in their cells, with the oil content excess of 20% biomass weight.
- This oil is commonly called *microbial oil*.
- It can be produced by some species of microalgae, bacteria, fungi and yeast.
- The main focus of research is on microalgae, fungi and yeast due to the yield of produced oil.
- Because the quantity of oil generated by bacteria is much lower, the interest in these organisms is not as high as for other microorganisms.
- The most advanced is work on technologies for producing biofuels from microalgae.

Microalgae

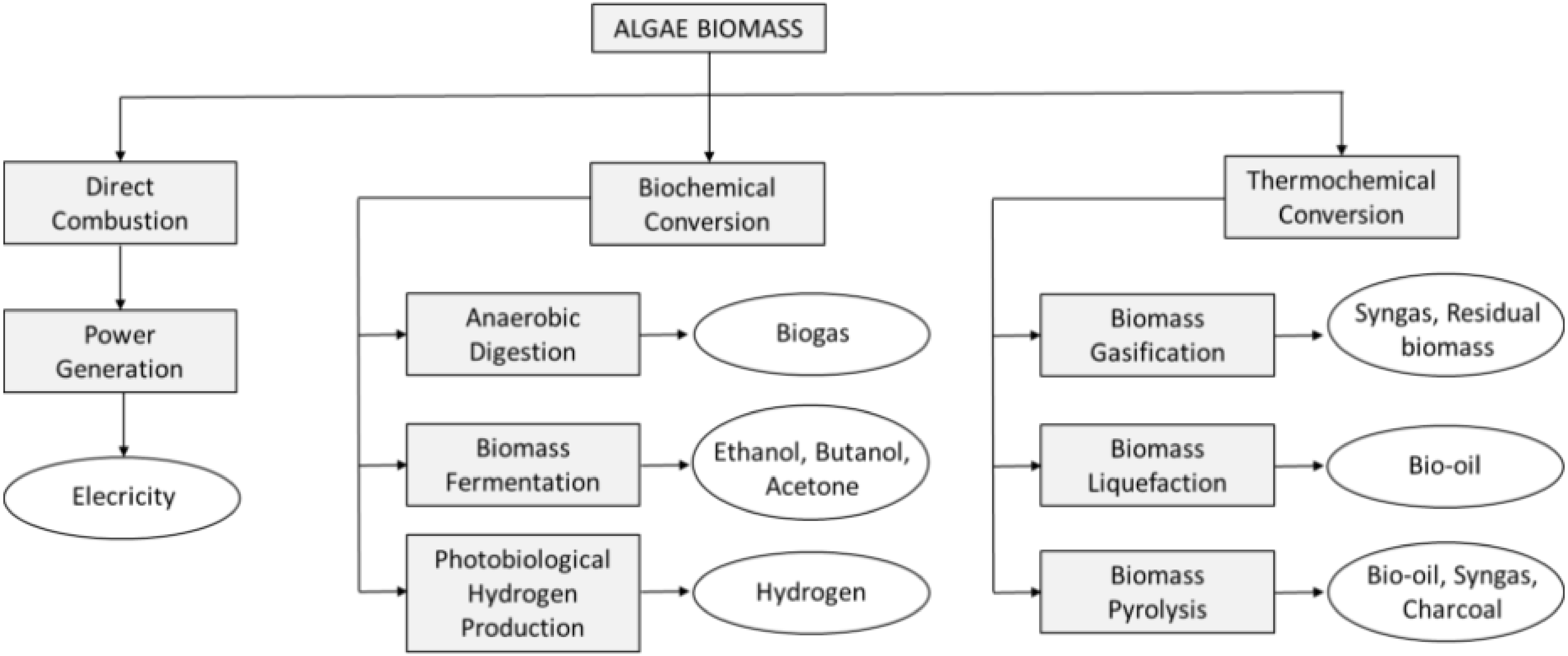
- They are present in all ecosystems and live under different environmental conditions.
- They are primitive unicellular form of plants.
- They do not have formed leaves, stems and roots. The cell structure of these species is very simple, which allows them to adapt to new environmental conditions relatively easy.
- The in-built chlorophyll in the cell of microalgae allows them to perform photosynthesis. But some species are heterotrophic and they require other sources of organic carbon and energy for growth. There are also mixotrophic microalgae, which, depending on the ambient conditions, can change their nutrition system from autotrophic to heterotrophic and vice versa.
- They differ among other species in cellular structure, life cycle and type of pigment.
- Two groups of microorganisms are classified as microalgae: prokaryotes and eukaryotes.
- The eukaryotes are divided into four main classes: the diatoms (*Bacillariophyceae*), the green algae (*Chlorophyceae*), the golden algae (*Chlorophyceae*) and the red algae (*Rhodophyceae*), whereas from prokaryotes to the microalgae group belong the cyanobacteria (*Cyanophyceae*).
- Despite the large number of species of these algae, in practice, only about 15 species are used for large-scale production processes

Open cultivation systems for cultivation of microalgae; left: Race way ponds; right: cascade system

Closed cultivation systems for cultivation of microalgae; left: sleeve-bag photobioreactor; right: tubular photobioreactor



General division of microalgae.

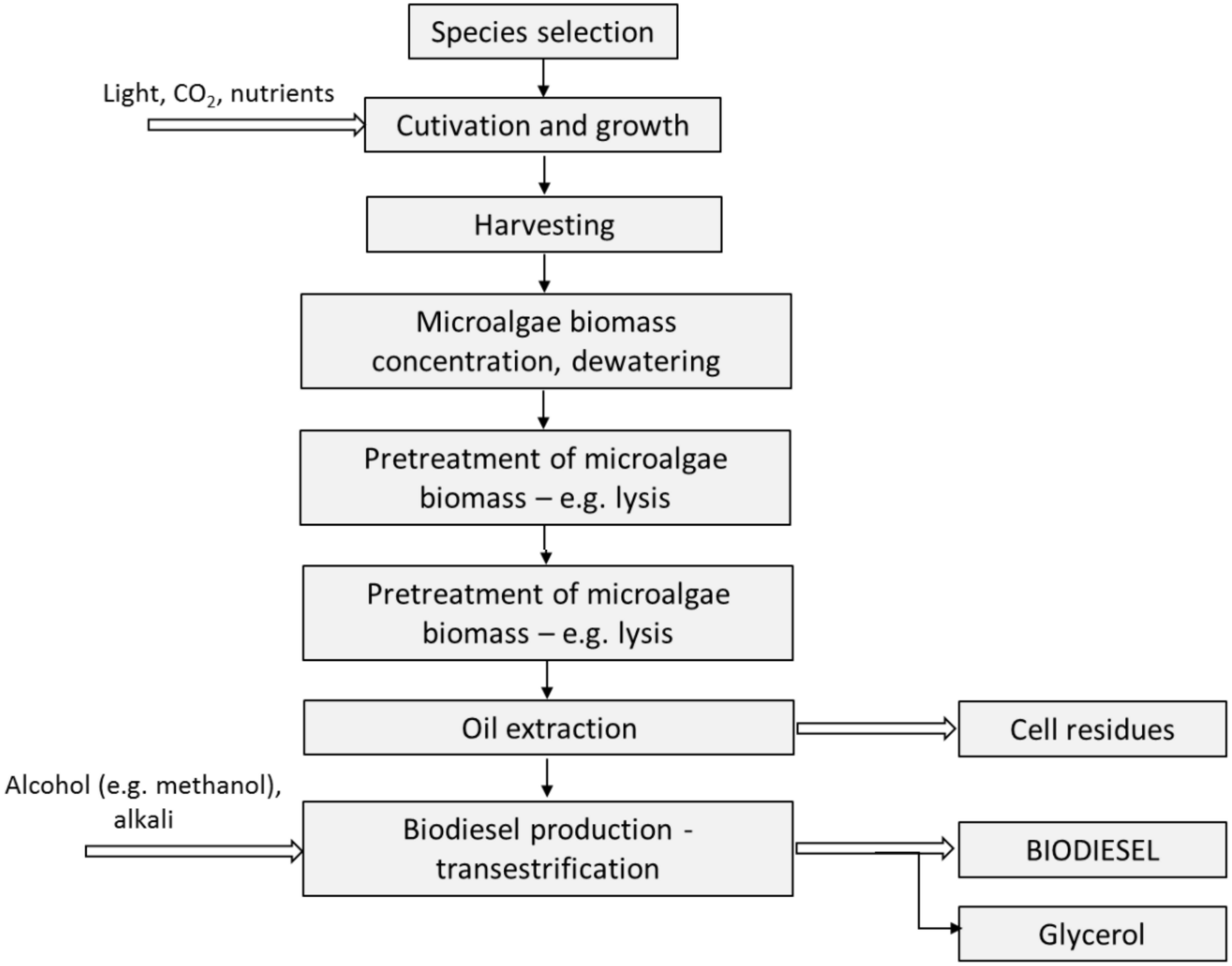


Potential for algal biomass conversion

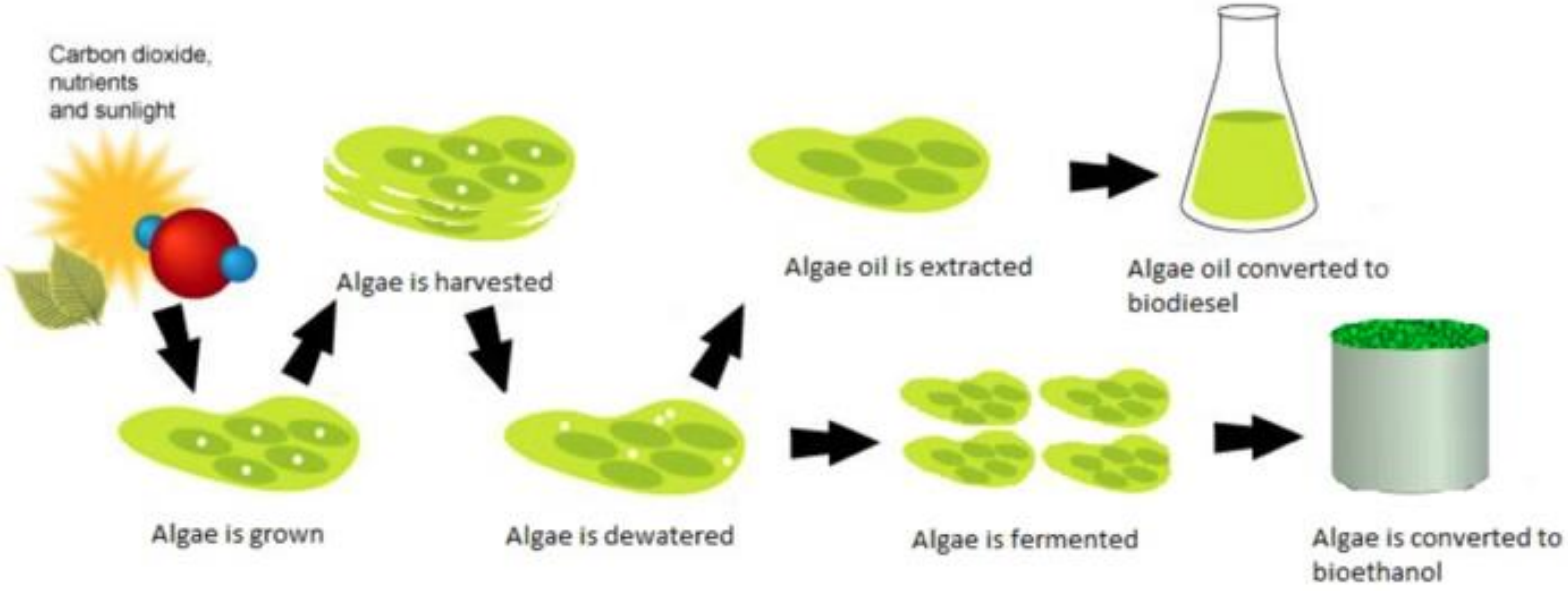
Syngas, or synthesis gas, is a mixture of hydrogen and carbon monoxide, in various ratios. The gas often contains some carbon dioxide and methane. It is principally used for producing ammonia or methanol. Syngas is combustible and can be used as a fuel.

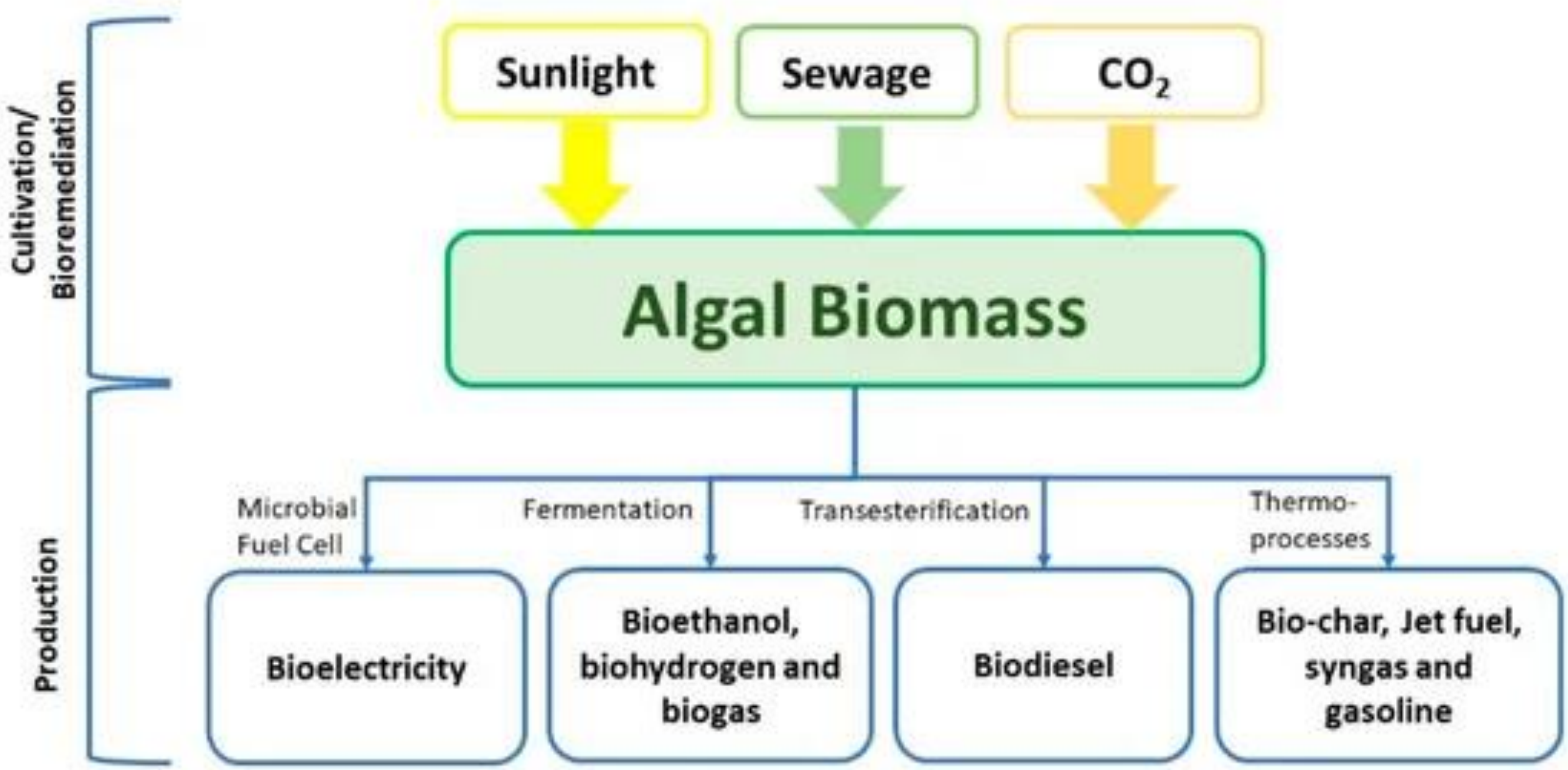
Biodiesel

- Generally, biodiesel is produced from oils extracted from oilseed crops or animals. **These oils are esters of fatty acids and glycerin**. **Biodiesel is produced by transesterification, where the glycerin is replaced with other alcohol (most often methanol or ethanol) in the presence of a catalyst. The result of the transesterification process is a mixture of fatty acid methyl (or ethyl) esters.**
- Since recently, **microalgae are being considered as a potential source of oils for biodiesel production**. They have the ability to accumulate lipids. Because lipids are basic raw material for biodiesel production, the oil content in cell should be taken into account for the microalgae selection process.
- **The oil content in cell depends on microalgae species and growth conditions. It can be as high as 80% dry weight**. **Microalgae need less land area for growing and have a higher yield of oil in comparison with oil crops.**
- For example, oil yield from soybean is 446 L/ha, from palm oil 5950 L/ha, but from microalgae produced in photobioreactors, the oil yield is 58,700 L/ha for species with 30% oil by weight in biomass and 136,900 L/ha for species with 70% oil by weight in biomass



Scheme of microalgae biodiesel production.


Carbon dioxide,
nutrients
and sunlight
Algae is harvested
Algae oil is extracted
Algae oil converted to biodiesel
Algae is grown
Algae is dewatered
Algae is fermented
Algae is converted to bioethanol


Cultivation/
Bioremediation
Sunlight
Sewage
CO_2
Algal Biomass
Production
Microbial
Fuel Cell
Fermentation
Transesterification
Thermo-
processes
Bioelectricity
Bioethanol,
biohydrogen and
biogas
Biodiesel
Bio-char, Jet fuel,
syngas and
gasoline

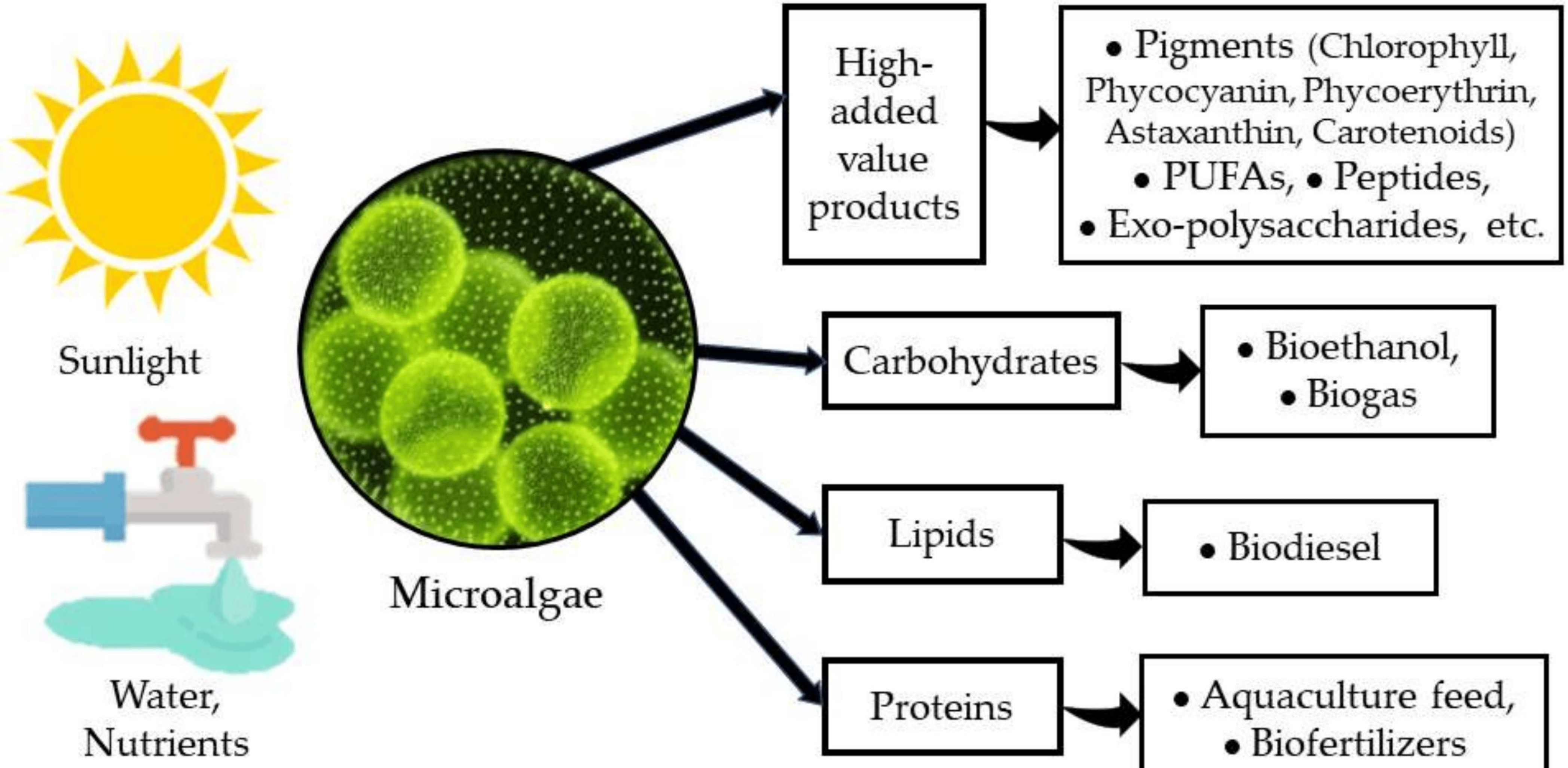
Biogas

- Microalgae in their cells also accumulate other components, for example, proteins, carbohydrates or starch, which are good nutriment for microorganisms producing biogas. Thus, these **algae as well as maize silage or wastes from processing of fruit and vegetables can be a good feedstock for anaerobic digestion process.**
- In recent years, two approaches to the production of biogas from microalgae have been investigated: (1) direct use of microalgae culture after concentration of the cells by filtration or centrifugation and (2) the use of cell residues, which remained after the extraction of oil or other components from microalgae.
- Microalgae, due to the enormous growth, **need very large amount of nitrogen and phosphorus to build their cells**. In the case of nitrogen, annual demand is estimated between 8 and 16 tones/ha, which is 55 to 111 times greater than in the case of rapeseed. It results in the fact that microalgae have a very big potential for the purification of water from the compounds containing N and P. **The phosphorus and nitrogen accumulated in the cells remain in biomass after extraction of oil. Methane fermentation makes it possible to release these elements from the microalgae cells and then applying them as nutrients in the algae cultivation. It reduces costs of algae production, and the recovered biogas additionally improves the economy of the company**.
- In addition to the high content of N and P, microalgae contain many other minerals (Fe, Co, and Zn), which not only meet the nutritional requirements of anaerobic microorganisms, but also stimulate their growth.

Butanol and ethanol

- Microalgae accumulate polysaccharides in their cells.
- **They are rich in various carbohydrates such as cellulose, starch, mannitol, agar and laminarin**. Some species contain a large amount (even over 50% of the dry weight) of starch and glycogen, which are essential for ethanol production. Such species include *Chlorella*, *Chlamydomonas*, *Dunaliella*, *Scenedesmus* and *Spirulina*.
- Ethanolic fermentation is performed mainly by yeast. Fermentation process for microalgae is similar to that for other plants. **The biomass is ground down, and the polysaccharides are converted to monosaccharides. Then, the yeast breaks down the sugars and converts them to ethanol.**
- Acetone–butanol fermentation is an anaerobic process of **enzymatic degradation of saccharides to butanol, acetone, carbon dioxide and hydrogen**. It is carried out by certain species of bacteria of the genus *Clostridium* (especially *C. butylicum* and *C. acetobutylicum*).
- **Generally, the whole process of alcohol production consists of pretreatment of the biomass, saccharification, fermentation and product recovery.**
- Quantity of produced alcohols depends on the production process parameters and characteristic of used algae biomass. For instance, the microalgae species such as *Chlorella* and *Chlorococcum* are better raw materials for ethanol production than *Chlamydomonas.*

- Ethanol from microalgae can be produced in three ways:
  i. from algae cell components (starch and saccharides) after their extraction or from cell wall components (cellulose) after enzymatic hydrolysis of walls,
  ii. some species of microalgae produce ethanol during dark fermentation and
  iii. via genetic modification of some microalgae to direct production of ethanol.
- In lack of light and in presence of oxygen, microalgae convert starch or glycogen by oxidizing them to carbon dioxide.
- But in dark, under anaerobic conditions, the oxidation is incomplete and different products (such as hydrogen, ethanol, formic acid and acetic acid) are produced.
- The proportion of particular compounds depends on the species of microalgae.
- Microalgae whose cells contain polysaccharides composed of glucose (e.g., *Chlamydomonas*, *Chlorella*, *Microcystis*, *Oscillatoria*, and *Spirulina*) are able to produce ethanol in the dark under oxygen-free conditions easily.
- The yield of alcohol production can be enhanced by appropriate pH and temperature range.



Sunlight
Water,
Nutrients
Microalgae
High-
added
value
products
• Pigments (Chlorophyll,
Phycocyanin, Phycoerythrin,
Astaxanthin, Carotenoids)
• PUFAs, • Peptides,
• Exo-polysaccharides, etc.
Carbohydrates
• Bioethanol,
• Biogas
Lipids
• Biodiesel
Proteins
• Aquaculture feed,
• Biofertilizers

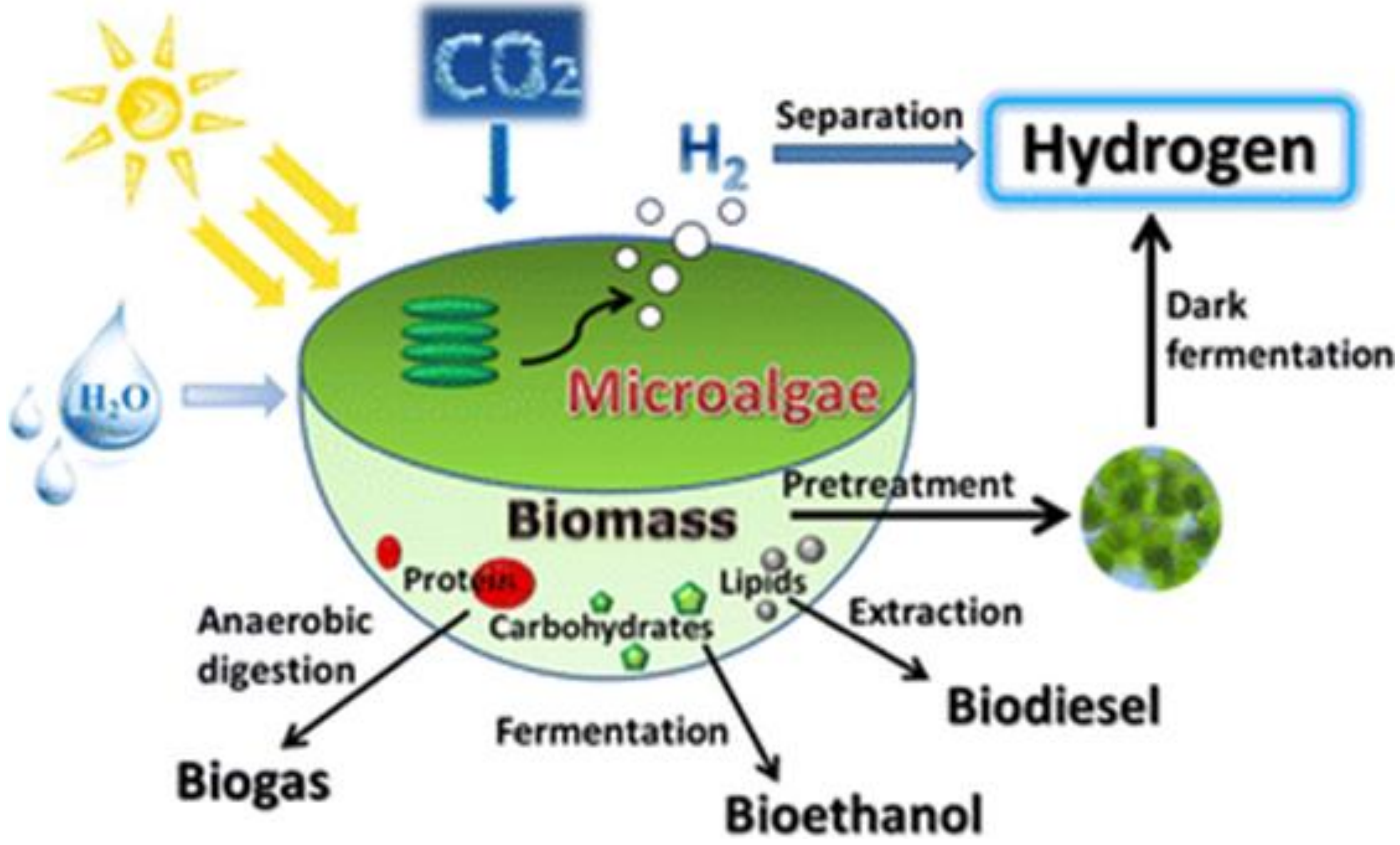
Hydrogen

- **Blue-green algae (cyanobacteria)** are promising microorganisms for this.
- Microalgae have capacity for producing hydrogen by photobiological reaction. The hydrogen is produced by direct or indirect photolysis of water:

  Direct photolysis: $2\ H_2O \rightarrow light \rightarrow 2\ H_2 + O_2$

  Indirect photolysis: $2\ H_2O + 6\ CO_2 \rightarrow light \rightarrow C_6H_{12}O_6 + 6\ O_2$

  $C_6H_{12}O_6 + 12\ H_2O \rightarrow 12\ H_2 + 6\ CO_2$.
- During photosynthesis, water molecules are converted by microalgae into hydrogen ions (H^+) and oxygen.
- Then the hydrogen ions are converted into hydrogen with the use of hydrogenase enzymes.
- The presence of oxygen results in rapid inhibition of the hydrogenase enzymes and the hydrogen production process is impeded.
- Therefore, cultivation of microalgae for H_2 production must be realized under anaerobic condition.
- Photosynthetic production of hydrogen can be carried out with the use of two-stage method. In this process the photosynthetic generation of O_2 and production of H_2 are separated.
  - In the first stage, the algae grow photosynthetically under normal conditions.



CO_2
H_2
Separation
Hydrogen
Dark
fermentation
H_2O
Microalgae
Pretreatment
Biomass
Protein
Lipids
Carbohydrates
Extraction
Anaerobic
digestion
Fermentation
Biodiesel
Biogas
Bioethanol

- During the second stage, the access to the sulphur is limited and microalgae are exposed to anaerobic conditions. Under S deprivation conditions, microalgae are fundamentally altering photosynthesis and cellular metabolism to survive. They consume internal starch and protein and produce hydrogen. This production process is limited with time, the yield of hydrogen decreases after 60 hours of production. The use of this method for hydrogen production does not generate any undesirable, toxic or environmentally harmful by-products.

- Another method for hydrogen production is a **continuous mode:**
  - In this mode, electrons and protons that are released during photosynthetic H2O oxidation are directly recombined by the hydrogenase to produce hydrogen. Theoretically, such a process is for 33% more efficient than two-phase method because in the two-phase process, electrons and protons released from water are storage (e.g., as starch) before being use to H2 generation.


Global Microalgae-based Products Market
Market Drivers
Increase in Demand for Microalgae in Nutraceuticals and Dietary Supplements
Rise in Demand for Microalgae in Production of Bio Fertilizers
US$ 2.4 Bn
In 2022(A)
Market Revenue
CAGR (2023–2031)
6.7%
By Product
Spirulina
Chlorella
Duninella Salina
Astaxanthin
Beta carotene
PUFA Fatty Acid
Lutein
Others
By Application
Food & Beverages
Personal Care
Nutraceuticals & Dietary Supplements
Pharmaceuticals
Chemicals
Fuel
Animal Feed
Others
Key Players
Cyanotech Corporation
Cargill, Inc.
EID Parry (India) Ltd.
euglena Co., Ltd.
AstaReal Group
BlueBioTech International GmbH
Far East Bio-Tec Co., Ltd.
Cellana Inc.
Ocean Nutrition
Algae Health Sciences - A BGG Company
Others
By Region
Europe
Largest market share in 2022
TRANSPARENCY MARKET RESEARCH
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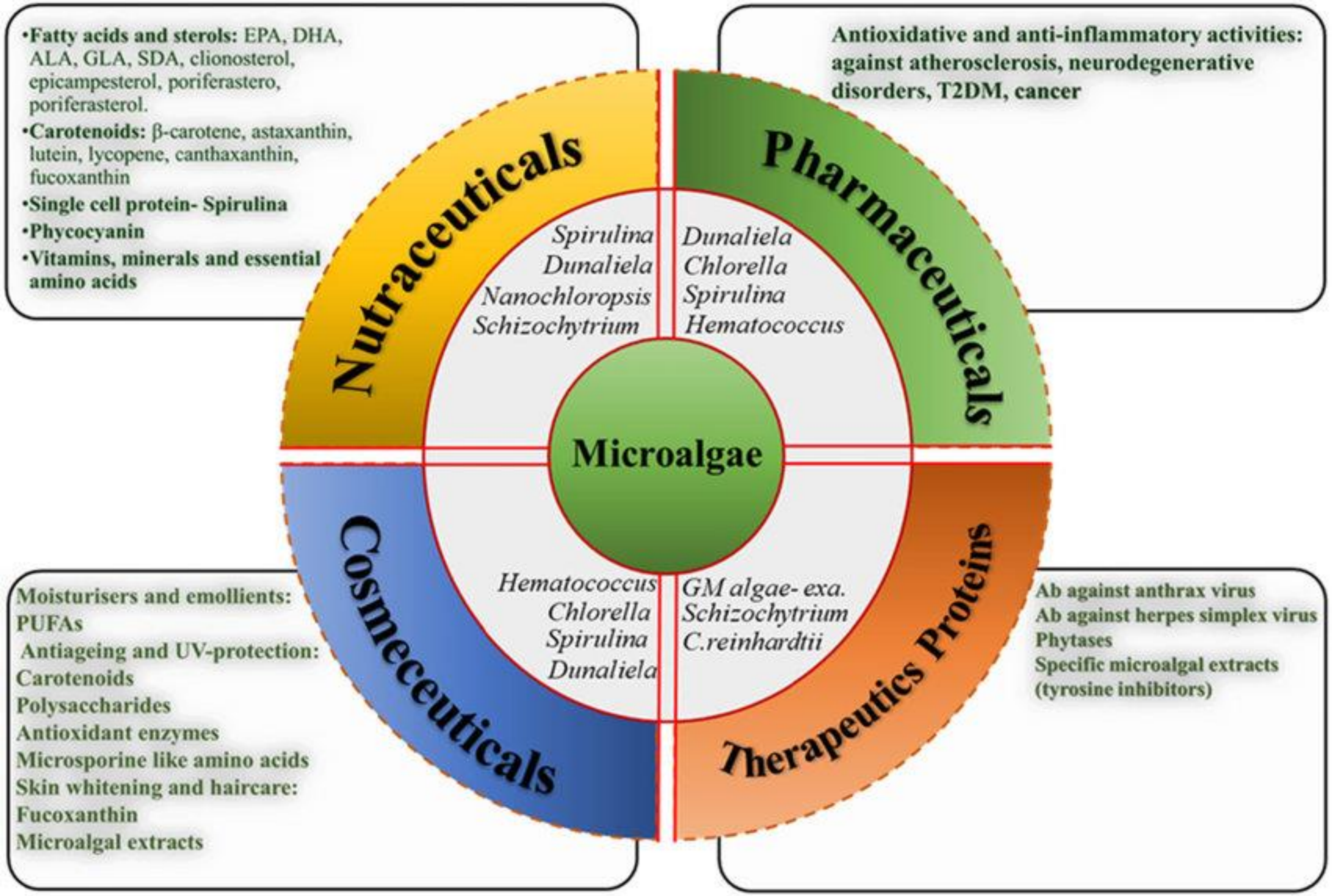
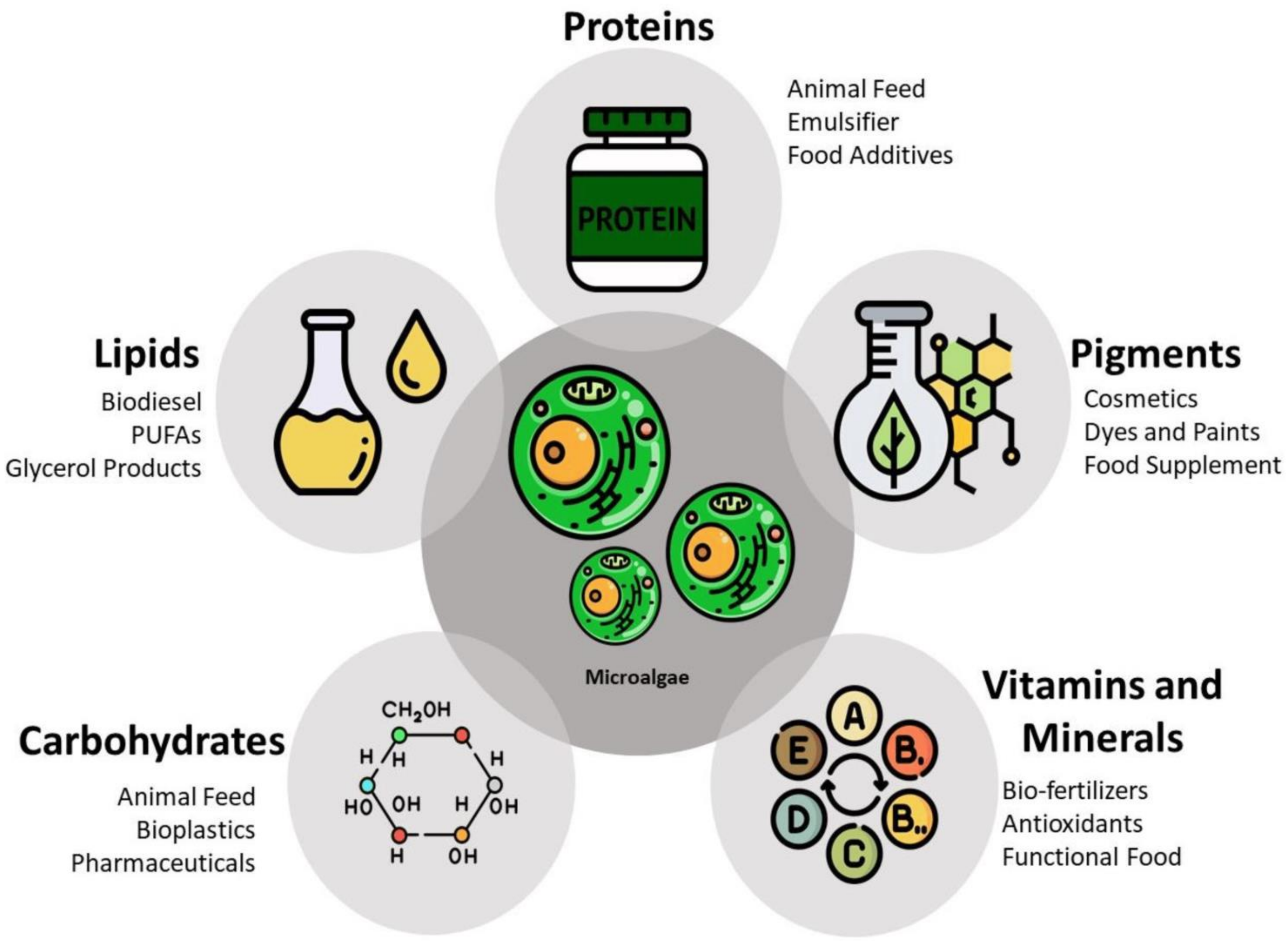


•Fatty acids and sterols: EPA, DHA, ALA, GLA, SDA, clionosterol, epicampesterol, poriferastero, poriferasterol.
•Carotenoids: β-carotene, astaxanthin, lutein, lycopene, canthaxanthin, fucoxanthin
•Single cell protein- Spirulina
•Phycocyanin
•Vitamins, minerals and essential amino acids
Antioxidative and anti-inflammatory activities: against atherosclerosis, neurodegenerative disorders, T2DM, cancer
Nutraceuticals
Pharmaceuticals
Spirulina
Dunaliela
Nanochloropsis
Schizochytrium
Dunaliela
Chlorella
Spirulina
Hematococcus
Microalgae
Cosmeceuticals
Therapeutics Proteins
Hematococcus
Chlorella
Spirulina
Dunaliela
GM algae- exa.
Schizochytrium
C.reinhardtii
Moisturisers and emollients:
PUFAs
Antiageing and UV-protection:
Carotenoids
Polysaccharides
Antioxidant enzymes
Microsporine like amino acids
Skin whitening and haircare:
Fucoxanthin
Microalgal extracts
Ab against anthrax virus
Ab against herpes simplex virus
Phytases
Specific microalgal extracts
(tyrosine inhibitors)


THE BENEFITS OF CHLORELLA
DRJOCKERS.COM
SUPERCHARGE YOUR HEALTH
PROMOTES BRAIN HEALTH
B vitamins, essential fatty acids and nutritional cofactors to combat memory loss & depression.
INCREASE ENERGY
Essential vitamins, minerals and amino acids to improve aerobic endurance and energy
BOOST IMMUNITY
Zinc, antioxidants and vitamins to strengthen and protect the immune system
ELIMINATES TOXINS
Antioxidants and chlorophyll to detoxify the body of chemicals and heavy metals
SUPPORTS FAT LOSS
High nutrient content to reduce cravings and lower cholesterol and blood glucose levels
REPAIRS & BUILDS MUSCLE
Natural vegan protein for rapid building, repair and recovery of body and muscle tissue
IMPROVES SKIN HEALTH
Key nutrients such as zinc and key antioxidants support skin health. Chlorella is the richest source of chlorella which helps cleanse and purify the body which improves skin health.


Proteins
Animal Feed
Emulsifier
Food Additives
PROTEIN
Lipids
Biodiesel
PUFAs
Glycerol Products
Pigments
Cosmetics
Dyes and Paints
Food Supplement
Microalgae
Carbohydrates
Animal Feed
Bioplastics
Pharmaceuticals
CH2OH
H
OH
HO
Vitamins and Minerals
Bio-fertilizers
Antioxidants
Functional Food
A
B.
B..
C
D
E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