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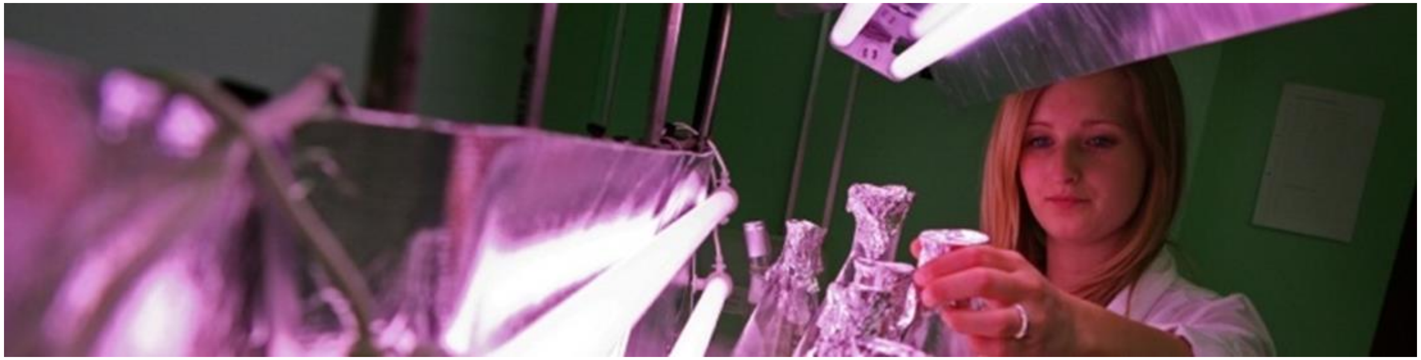

Biofuels production From the first to the third generation.

Anne-Lise Hantson
UMONS – Chemical and Biochemical Process Engineering Unit
anne-lise.hantson@umons.ac.be

Avec le soutien de la DGO6
Département du développement Technologique
Wallonie
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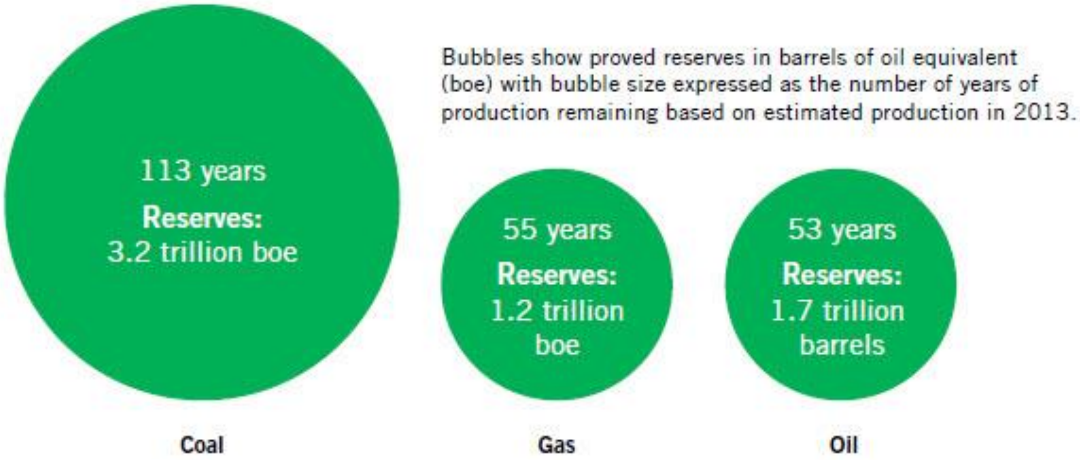
LE FONDS EUROPÉEN DE DÉVELOPPEMENT RÉGIONAL ET LA WALLONIE INVESTISSENT DANS VOTRE AVENIR

Plan

- ✓ Introduction
- ✓ Biofuel generations and feedstoock
- ✓ 1G – biofuel production
- ✓ 2G - biofuel production
- ✓ 3G – biofuel production
- ✓ PBR integration in buildings
- ✓ Sustainability with biorefinery concept
- ✓ Conclusions

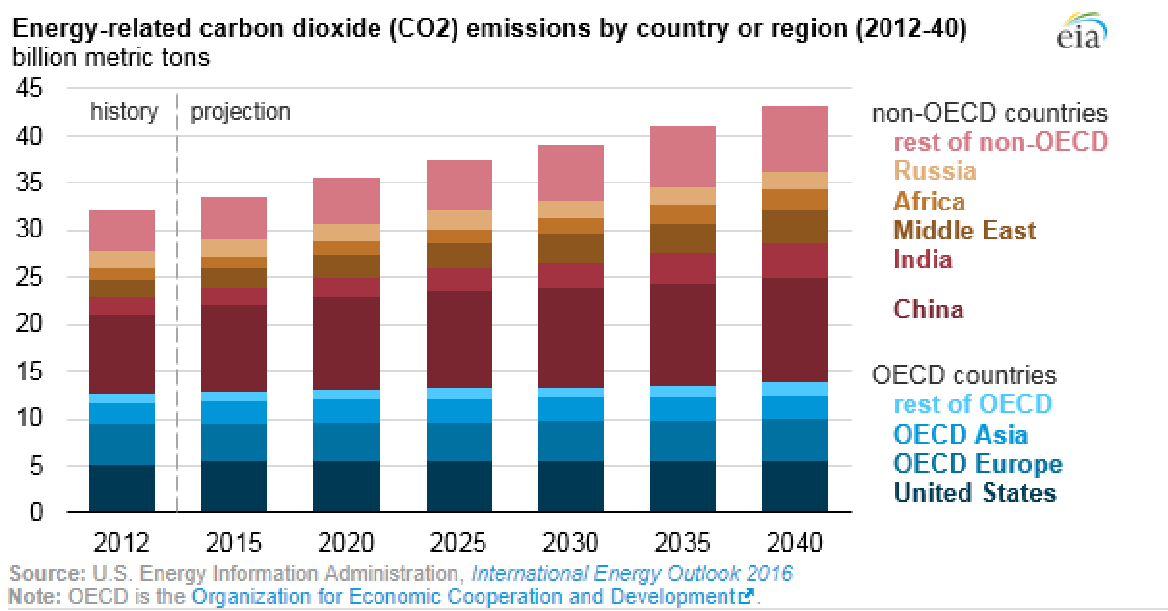
Introduction



Limitation of the fossil ressources

Source: BP, 2014. *Statistical Review of World Energy.* (Note: one trillion = one thousand billion).

Projection of energy-related CO_2 emission



CO_2 Production and Biomitigation

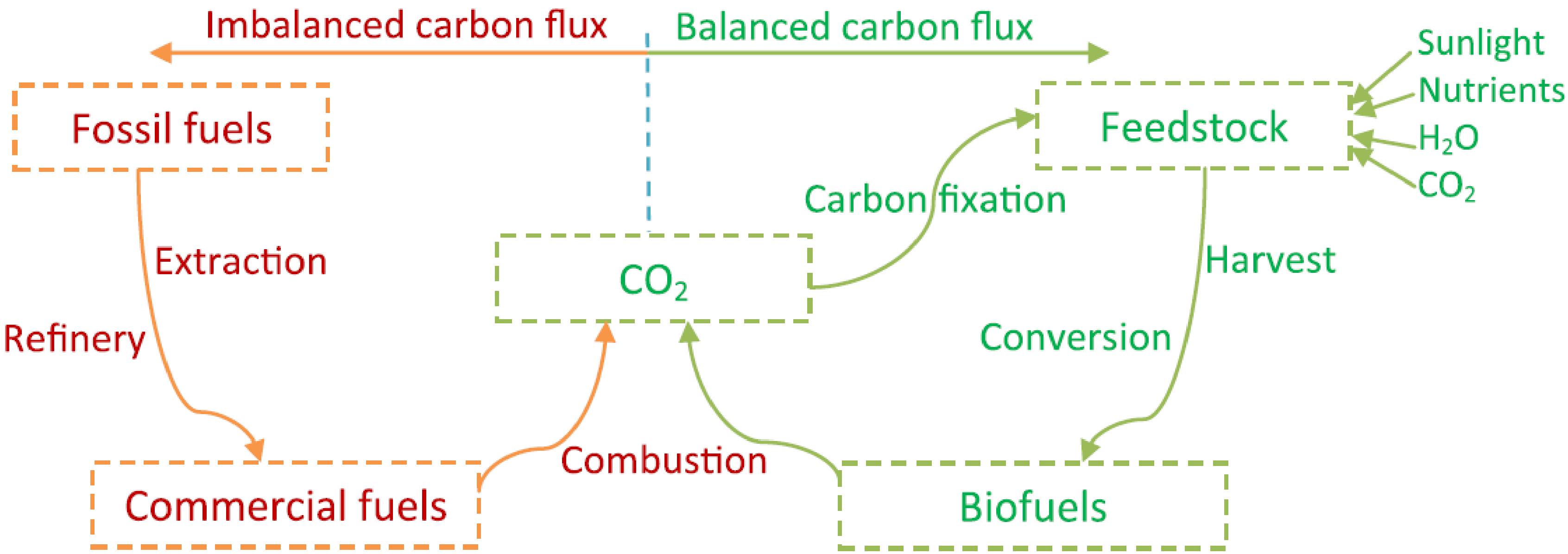


Fig. 2. CO_2 cycle for fossil fuel and biofuels.

Biofuels definition :

Biofuels are fossil fuel substitutes that can be made from a range of agricultural crops and other sources of biomass. The two most common current Biofuels are ethanol and biodiesel.

Four Biofuel Generations

- First Generation (1G) biofuels are mainly produced from edible feedstock from agricultural technologies

  Fully commercialized

- Second Generation (2G) biofuels are produced from non edible feedstock from advanced conversion technologies.

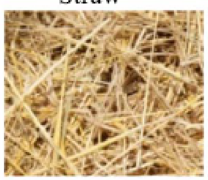
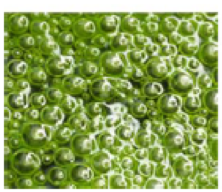
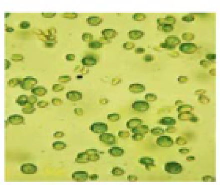
  Under commercialization

- Third Generation (3G) biofuels are produced from CO_2 neutral feedstock from advanced technologies.

  Under development

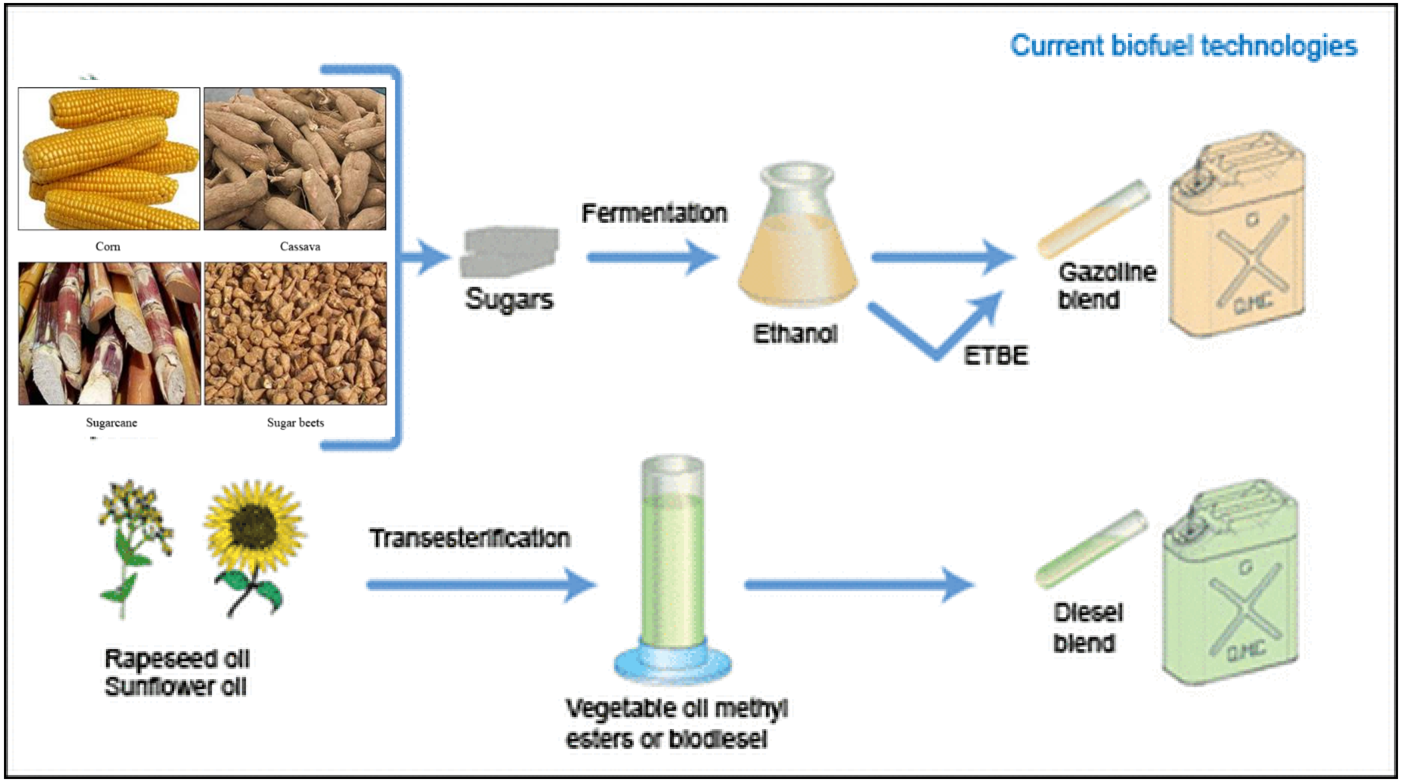
- Fourth Generation (4G) are produced from CO_2 negative feedstock (emphasis in CO_2 storage).

Comparaison between the 3 first generations of biofuels based on their feedstock

Generations of Biomass Feedstock	Prosperities
1st Generation (food crops)	
Starchy Materials: Corn  Sucrose-Containing Feedstocks: Sugar Beet  Sugar Cane 	1. Produced mainly from agricultural crops traditionally grown for food and animal purposes 2. Causes food crisis and contributes to higher food prices, carbon stores, and land use
2nd Generation (waste and energy crops)	
Lignocellulosic biomass Wood residues  Straw  Energy Crops 	1. Produced from non-edible crops grown on non-arable land 2. Produced from wood waste, agricultural waste, energy crops, organic waste, waste water, and landfill wastes 3. Harder to extract the required fuel
3rd Generation	
Algae   	1. Most microalgae grow through photosynthesis by converting sunlight, CO2, and a few nutrients, including nitrogen and phosphorous, into biomass 2. Algae can be grown using non-arable land and water unsuitable for food production (brackish, sea and wastewater), therefore reducing the strain on already depleted water sources 3. High yield per acre 4. Minimal impact on fresh water resources 5. Using CO_2 emissions from power plants 6. The oil productivity of microalgae is greater than that of other energy crops

G.M. Elrayies - Renewable and Sustainable Energy Reviews 81 (2018) 1175–1191

First Generation Biofuels – Production Scheme



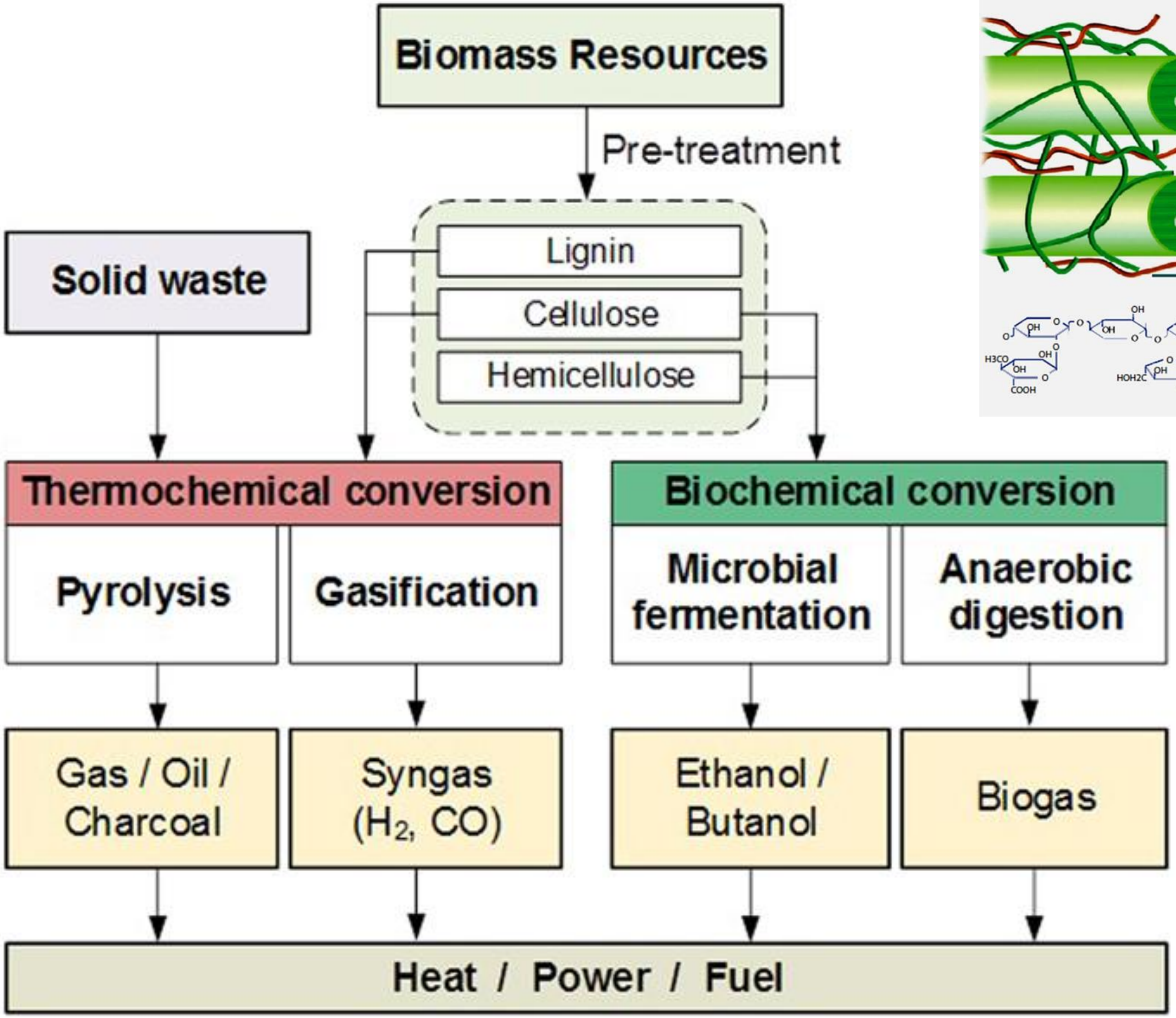
➢Biofuel made from sugar, starchy crops, vegetable oil or animal fat using conventional technology.

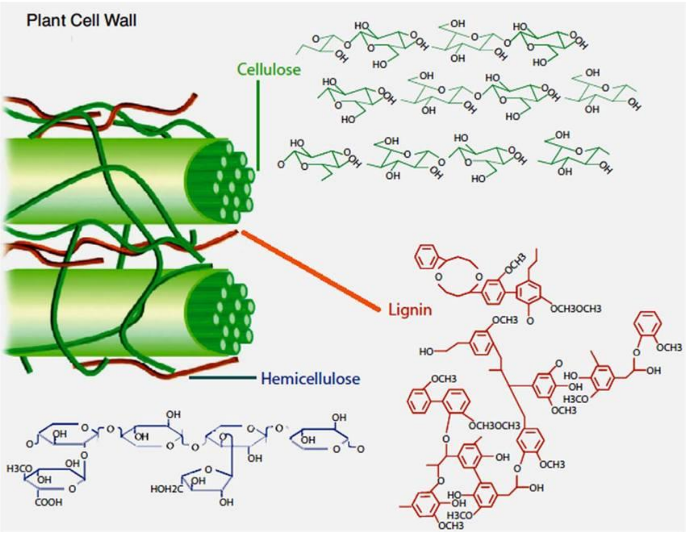
➢The starch from the basic feedstocks is fermented into bioethanol, or the vegetable oil through chemical process to biodiesel.

➢These feedstocks could instead enter the animal or human food chain.

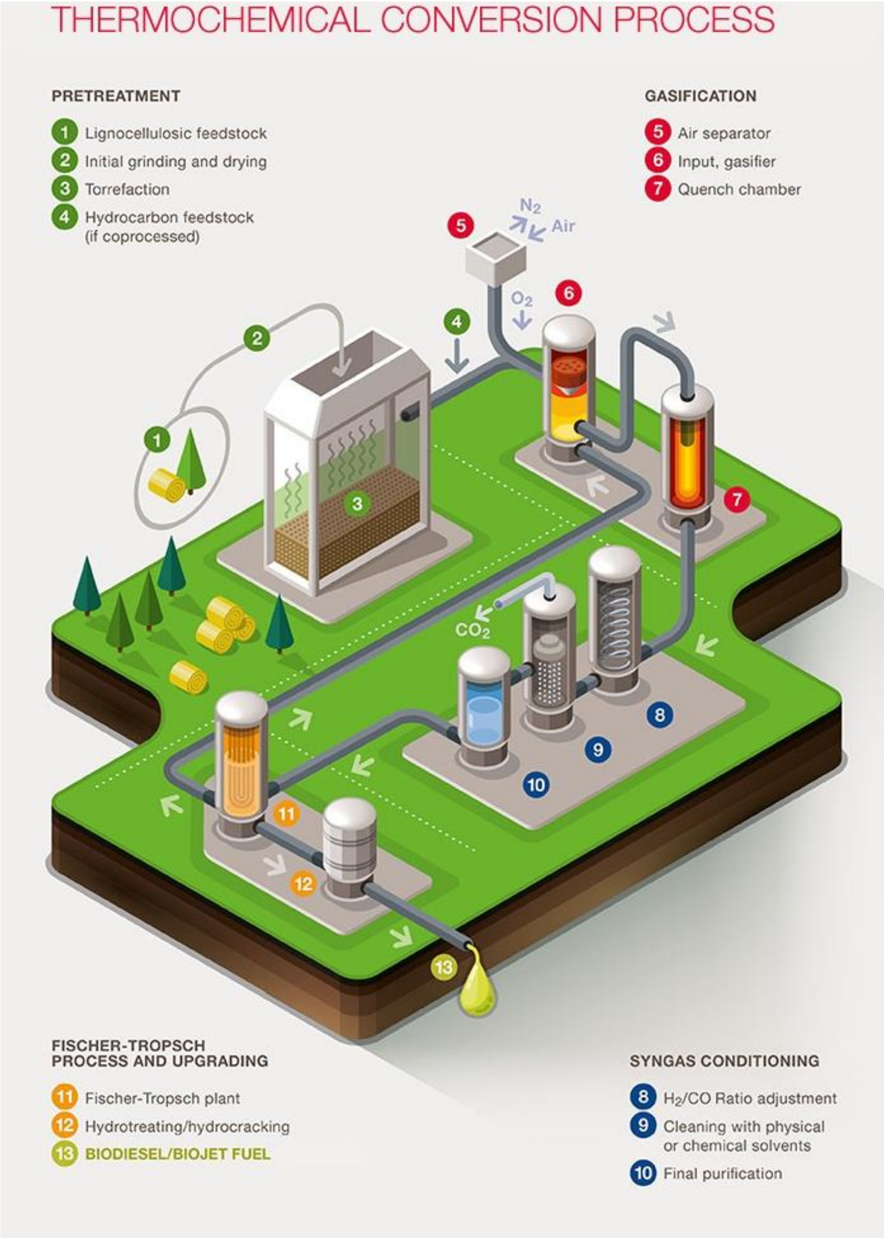
➢They don't seem to be more environment friendly than the fossil fuels.

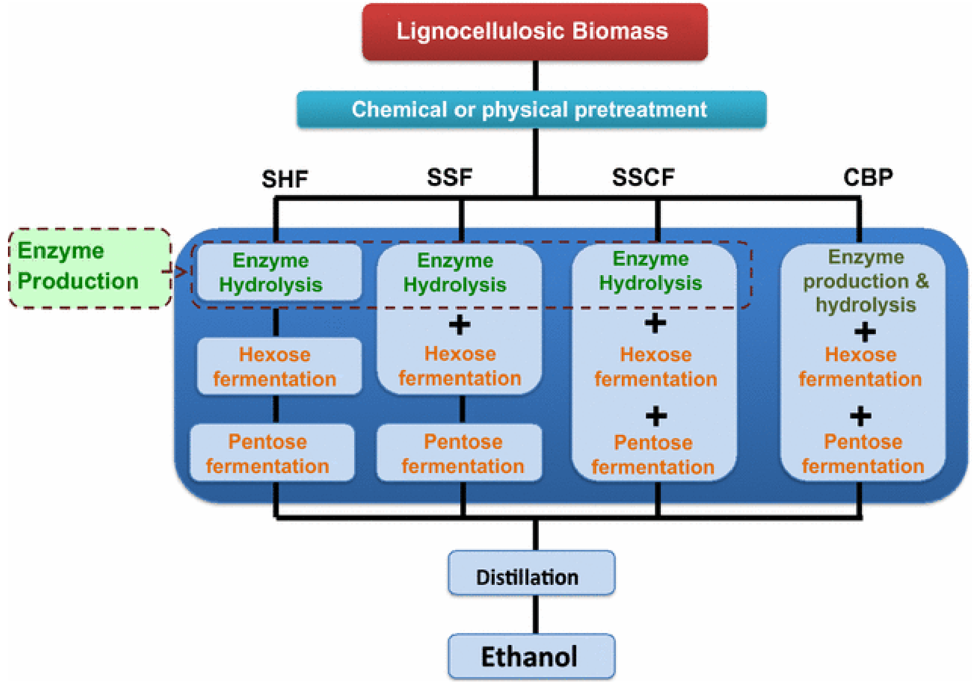
Second Generation biofuel based on lignocellulosic biomass





Biochemical conversion process





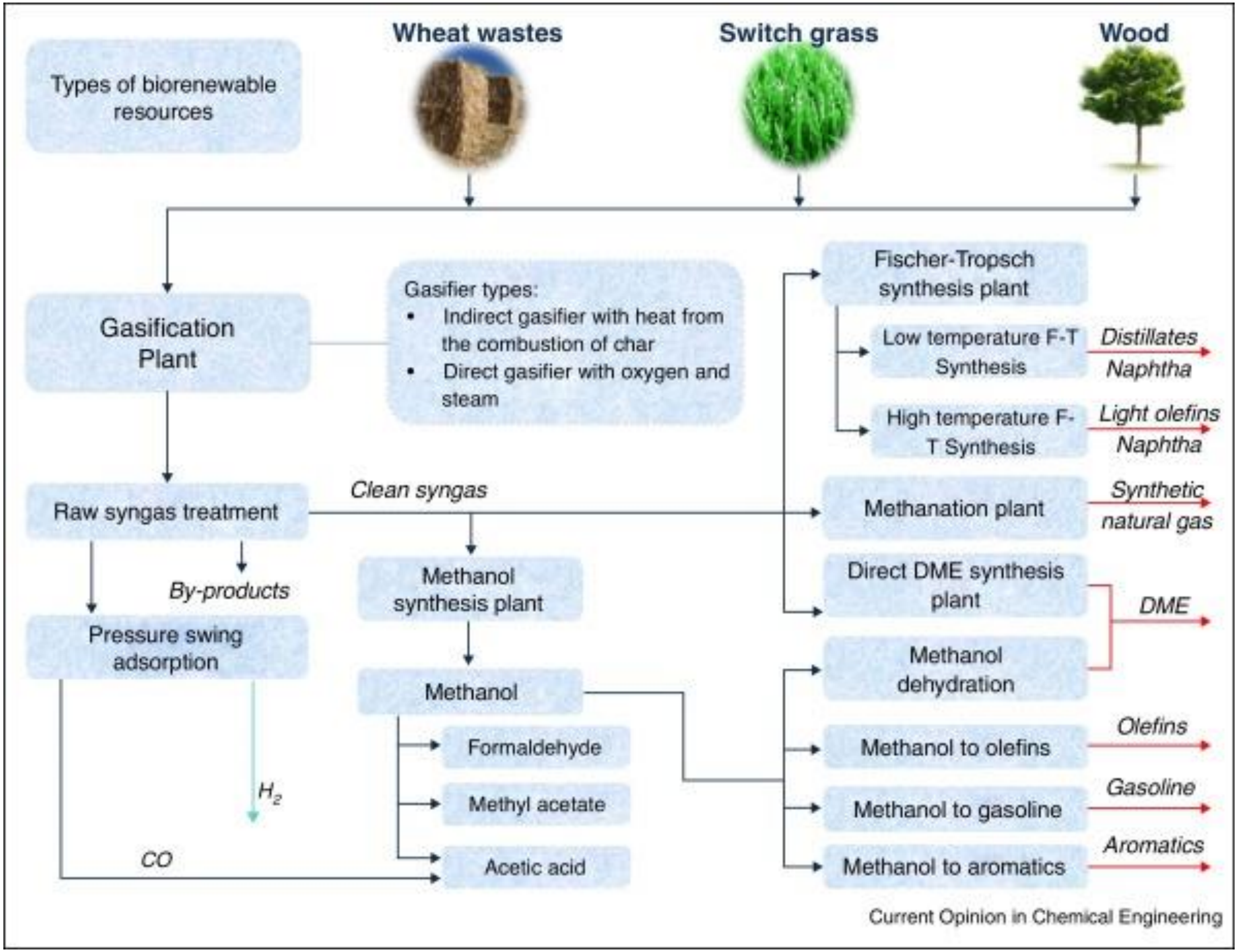
$$C_6H_{12}O_6 \xrightarrow{\textit{Saccharomyces cerevisiae}} 2C_2H_5OH + 2CO_2$$

Glucose	Ethanol	Carbon dioxide
1 kg	0.51 kg	0.49 kg

$$3C_5H_{10}O_5 \xrightarrow{\text{Pentose fermenting microorganisms}} 5C_2H_5OH + 5CO_2$$

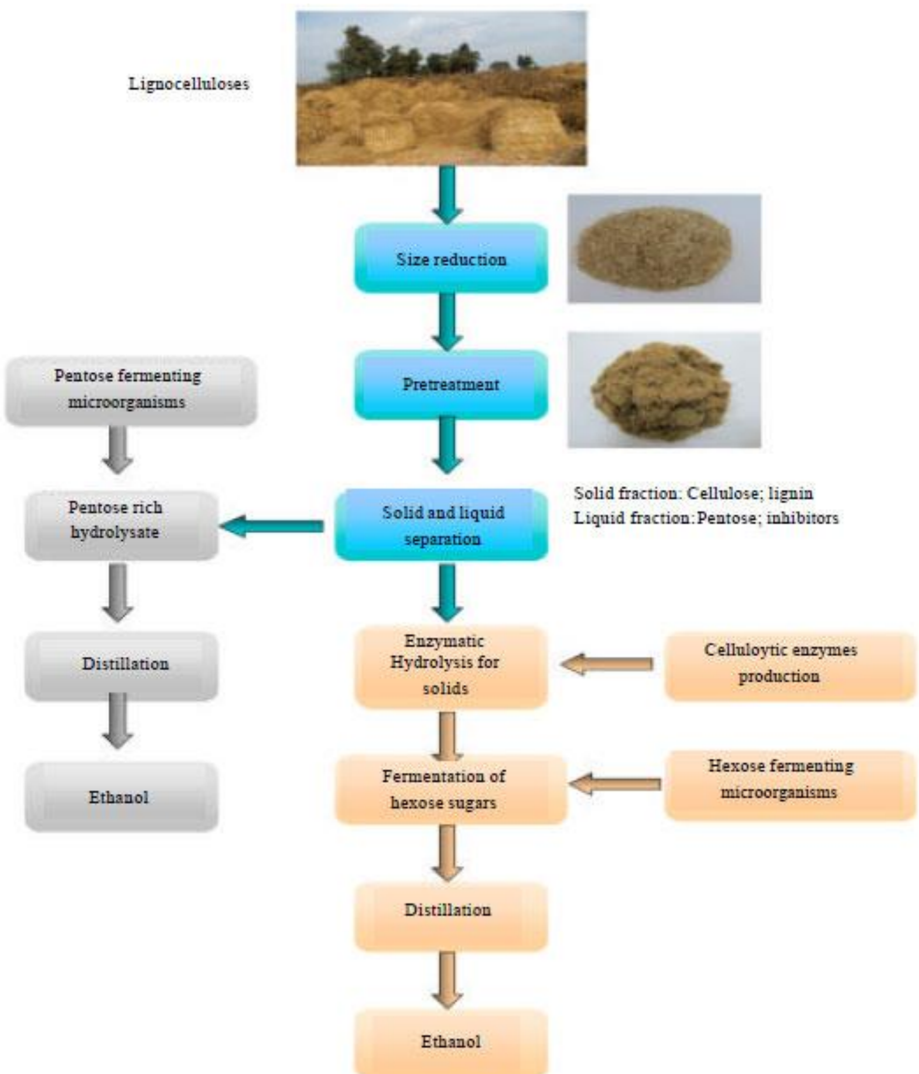
Pentose	Ethanol	Carbon dioxide
1 kg	0.49 kg	0.51 kg

Thermochemical Processes

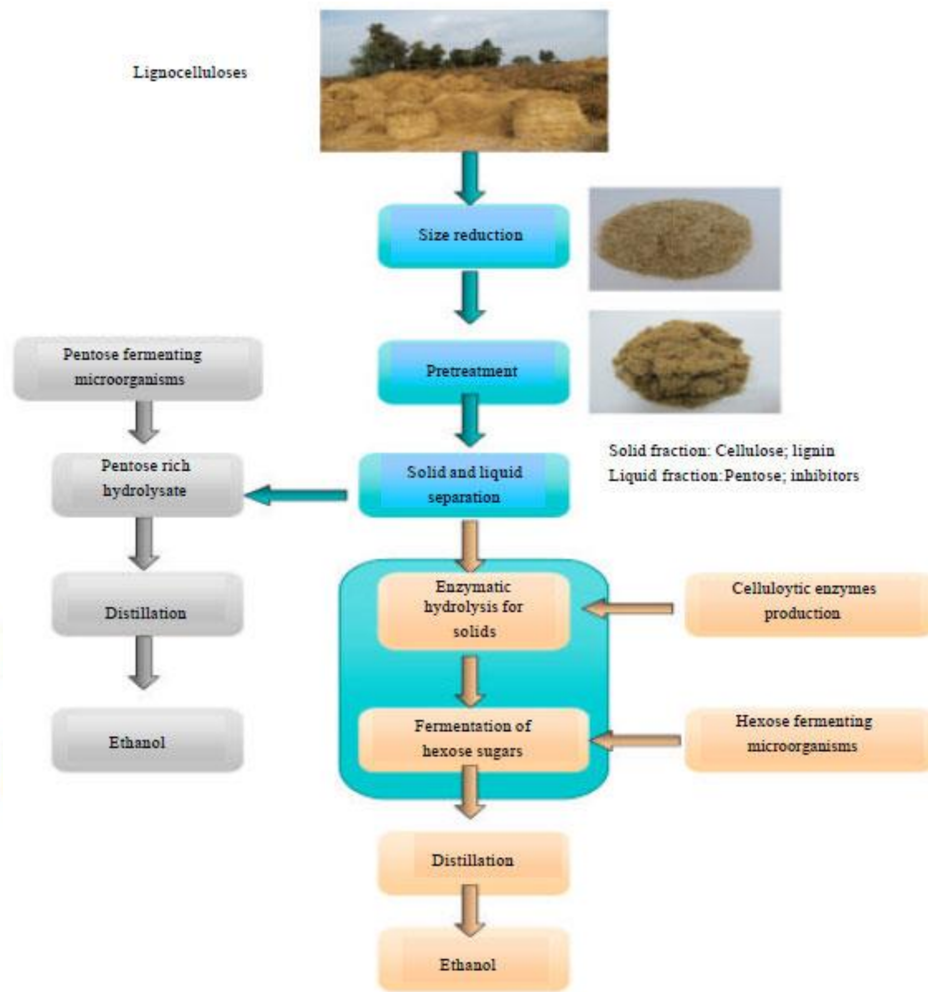


M. El-Halwagi, K. Ming Ng, Current Opinion in Chemical Engineering 2015, **10**:70–76

Schematic demonstration of bioethanol production using separate enzymatic hydrolysis and fermentation (SHF)

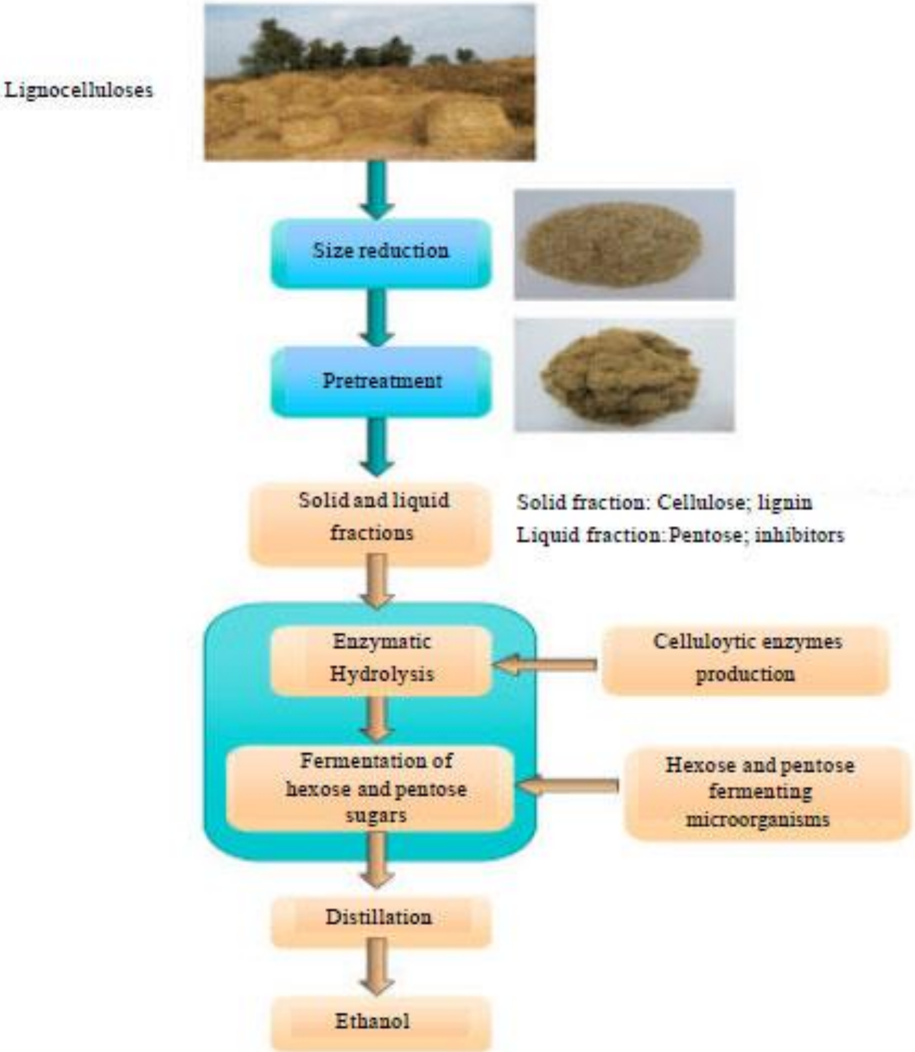


Schematic demonstration of bioethanol production using simultaneous saccharification and fermentation (SSF)

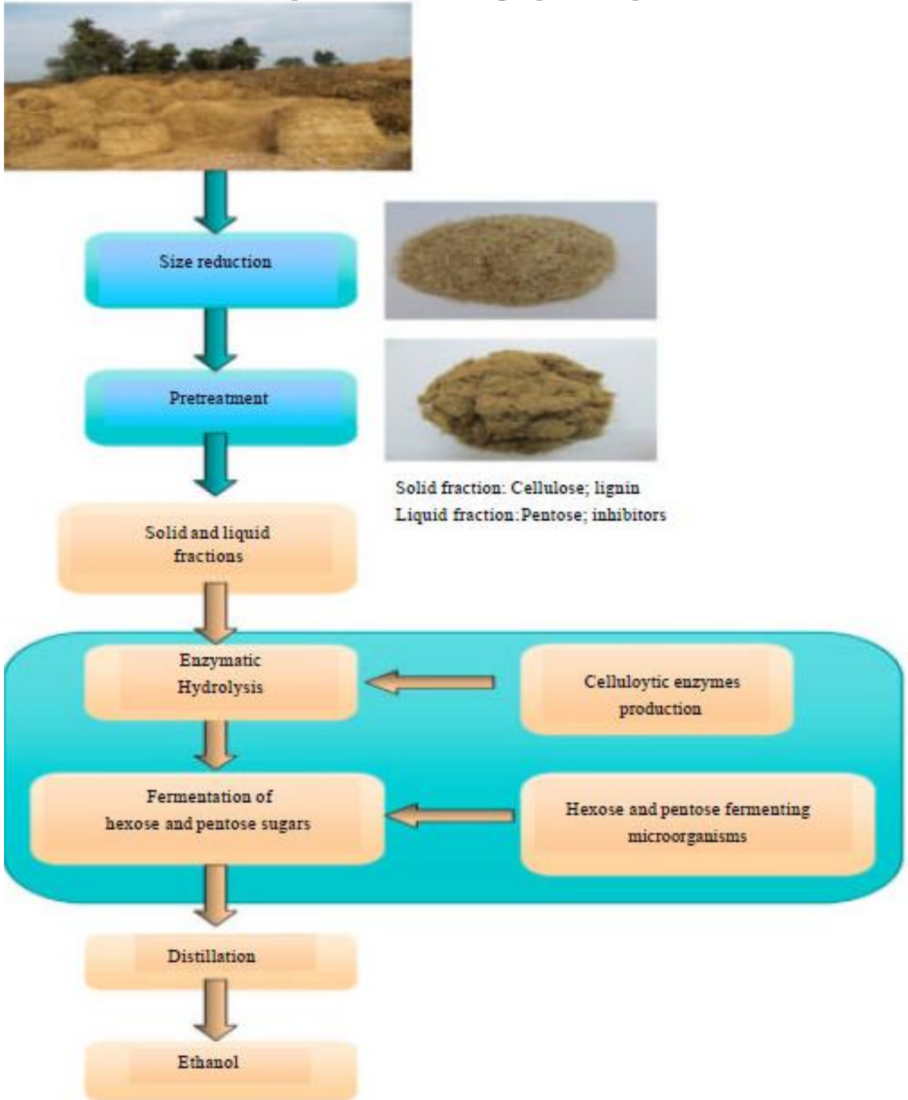


N. El-Ahmady et al. Biotechnology 13 (1):1-21 (2014)

Schematic demonstration of bioethanol production using simultaneous saccharification and cofermentation (SSCF)



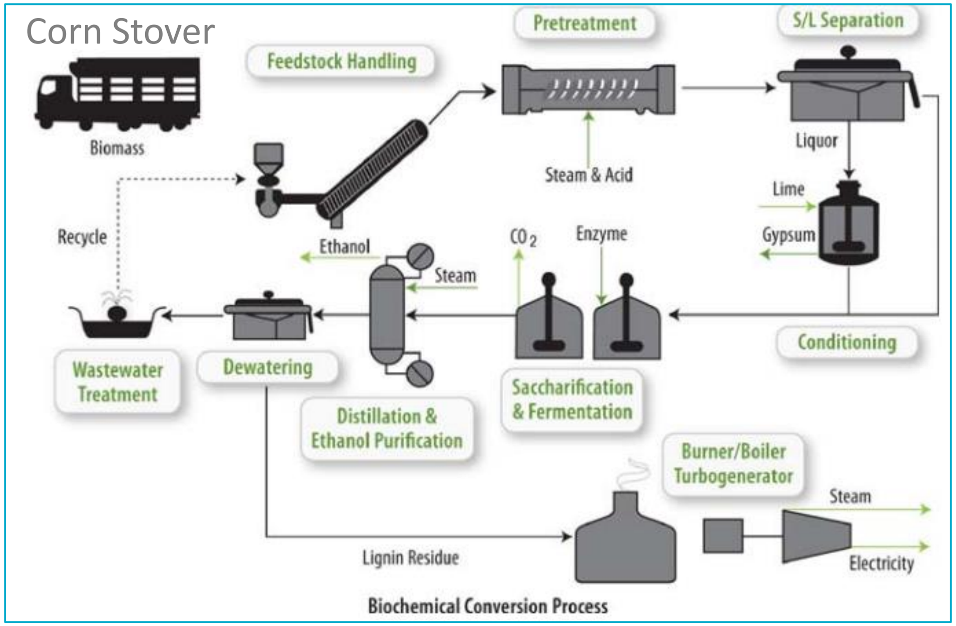
Schematic demonstration of bioethanol production using consolidated bioprocessing (CBP)

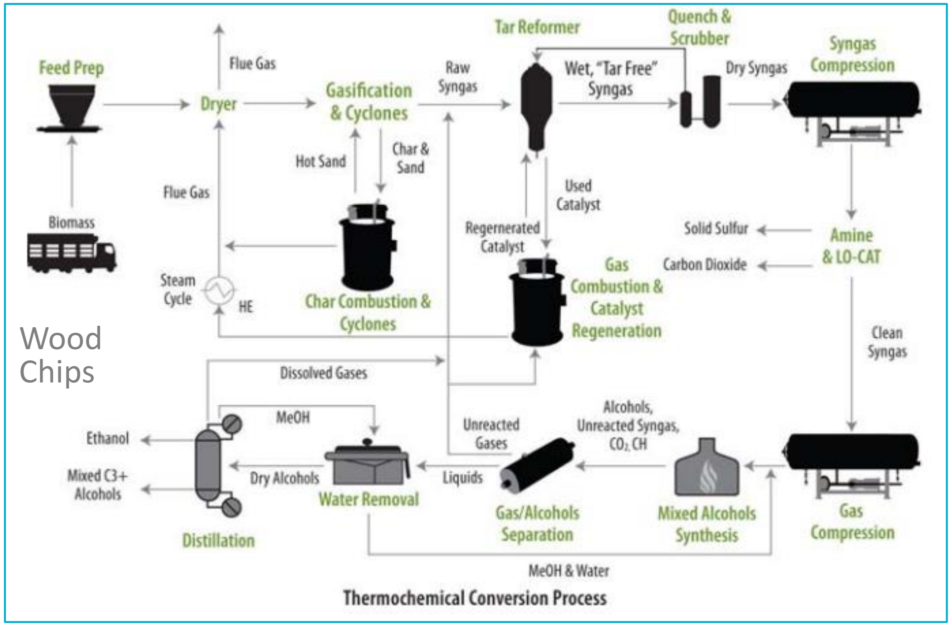


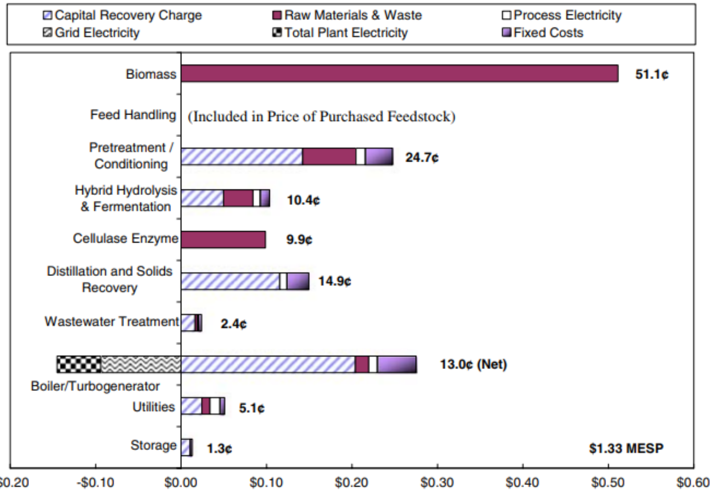
N. El-Ahmady et al. Biotechnology 13 (1):1-21 (2014)

Comparaison between thermochemical and biochemical production of bioethanol

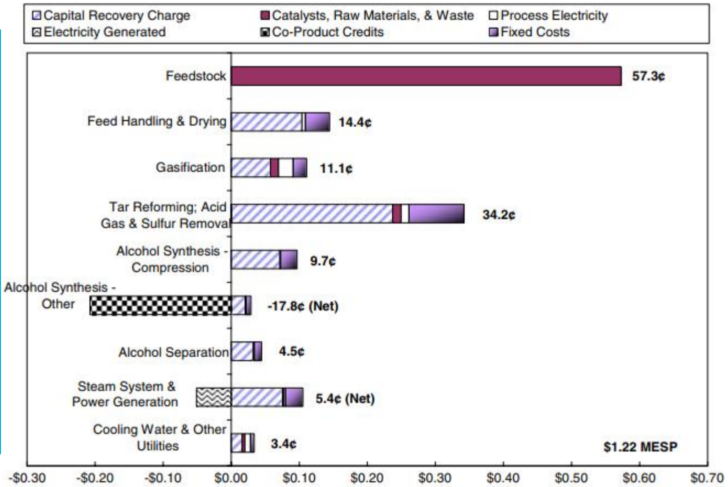
Cellulose (2009) 16:547–565







An overall cost, efficiency, and environmental perspective, these two biomass conversion processes analyzed here are essentially similar within the margin of error.



Third Generation Biofuel based on Microalgal Biomass

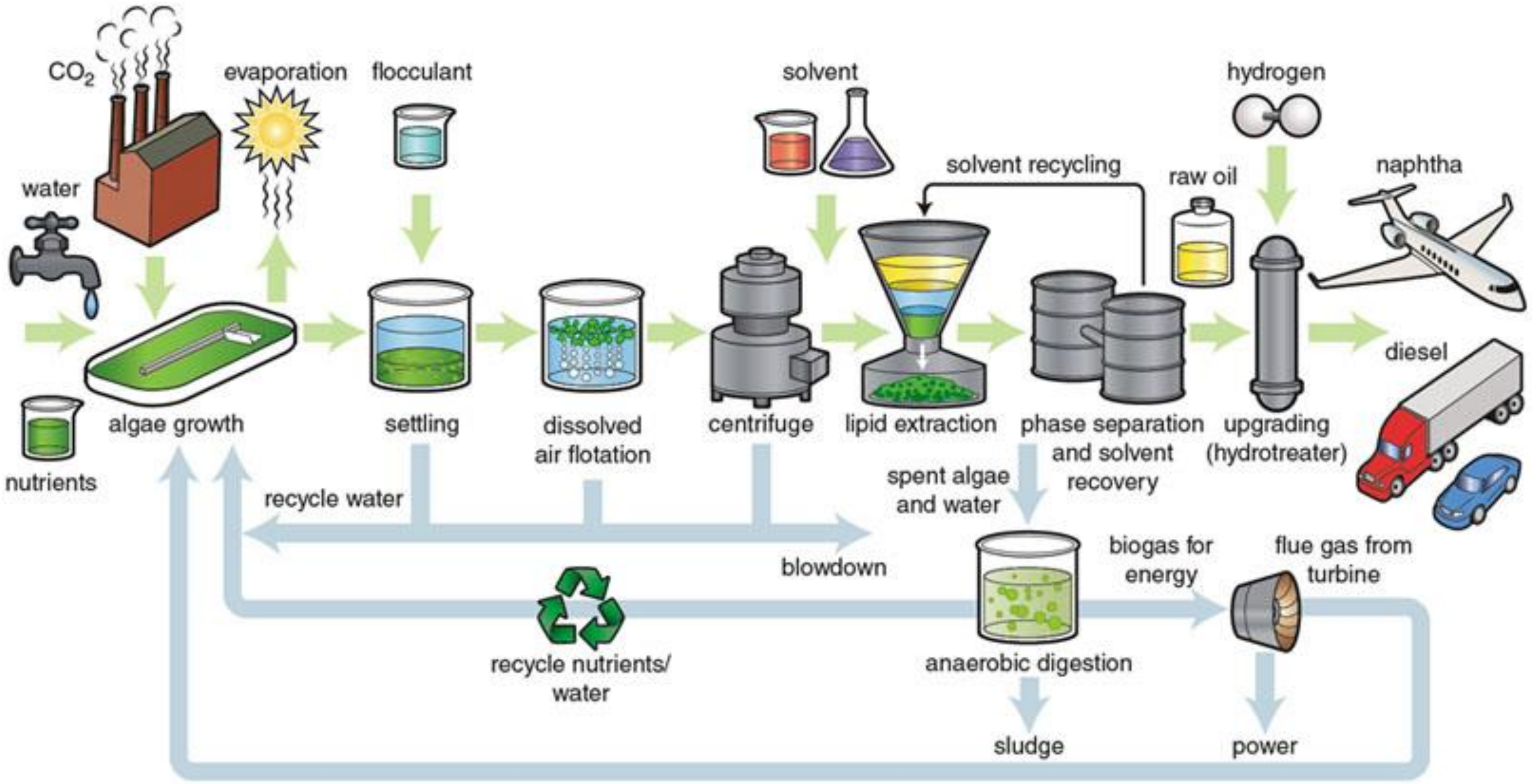
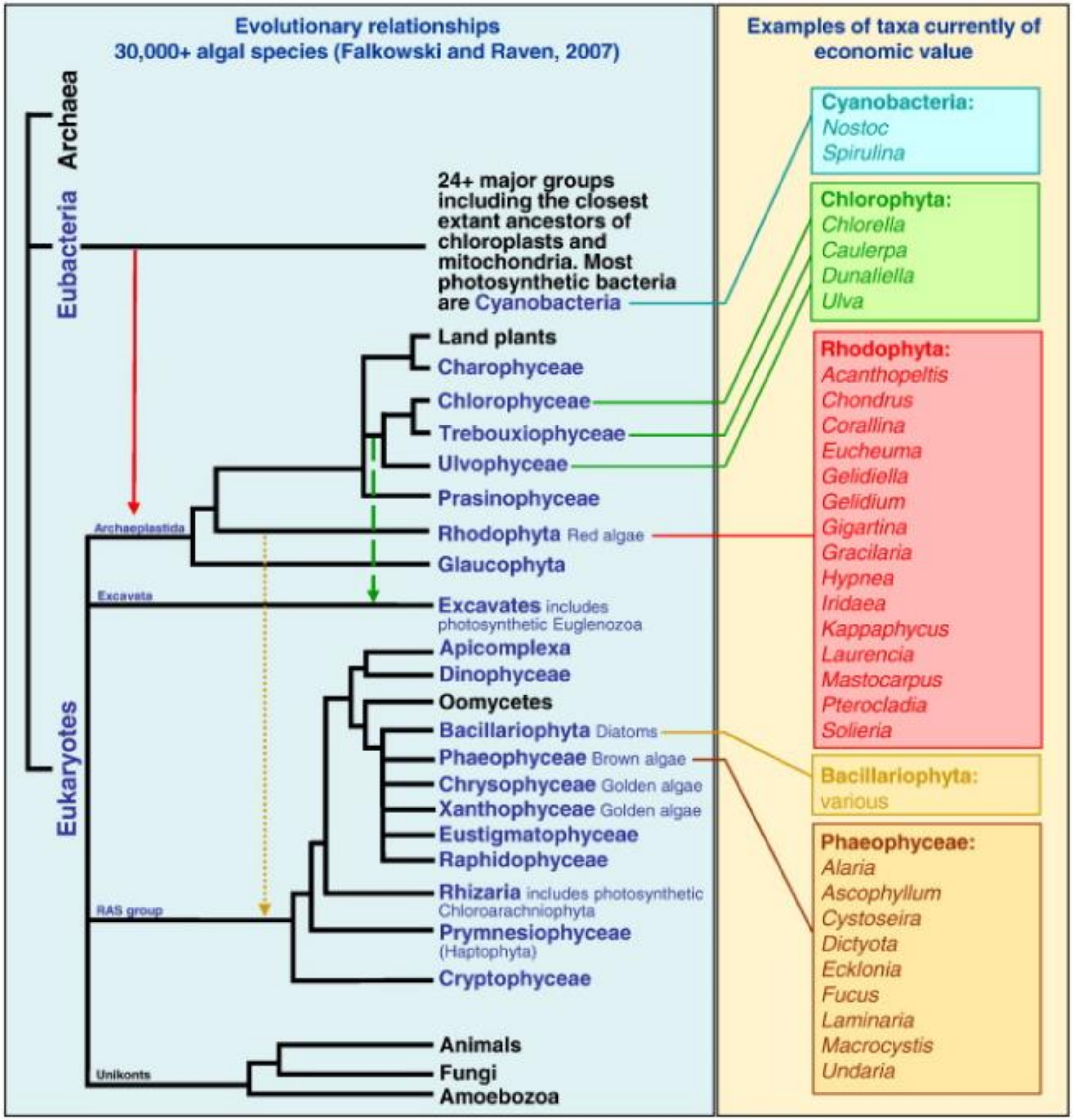
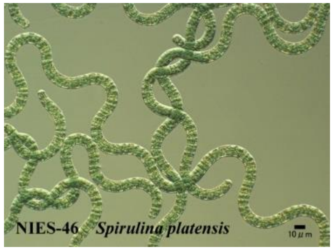


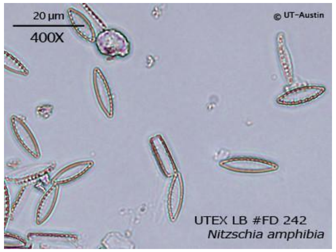
Illustration : Barbara Aulicino. America Scientist November-decembre 2011-99 (6) 474.

Algae : Polyphyletic group of organisms

D.B. Stangel et al. Biotechnology Advances 29 (2011) 483–501

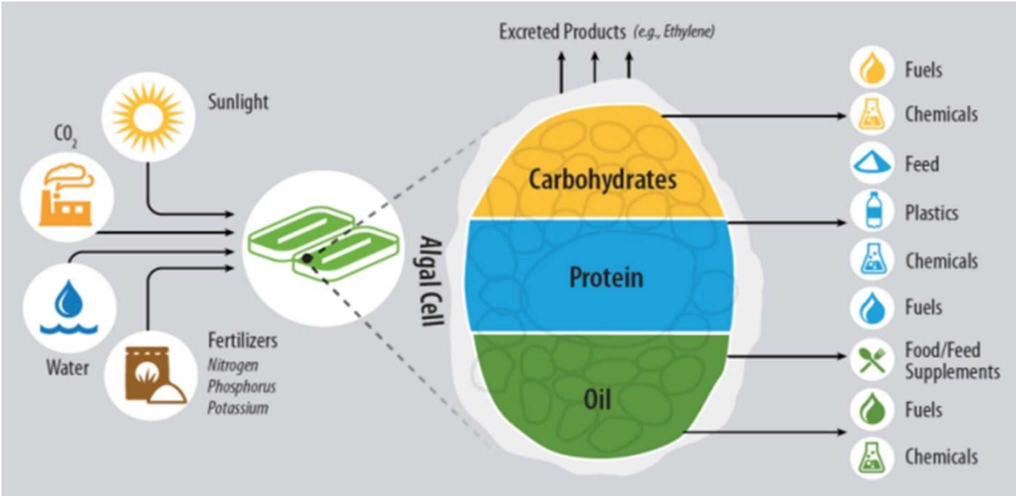






Biochemical composition

High plasticity to direct bioproduction to specific fatty acids or other metabolites of interest



Factors affecting biochemical composition

- Light (photo-period and intensity)
- Temperature
- Nutrient-status (nitrogen availability, waste water, flue gas)
- Nutrition (media)
- Salinity
- Carbon availability (CO_2 or organic carbon)
- Growth phase

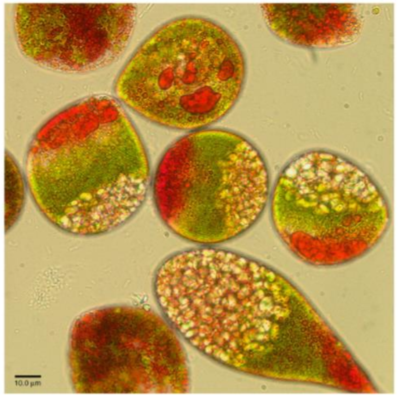
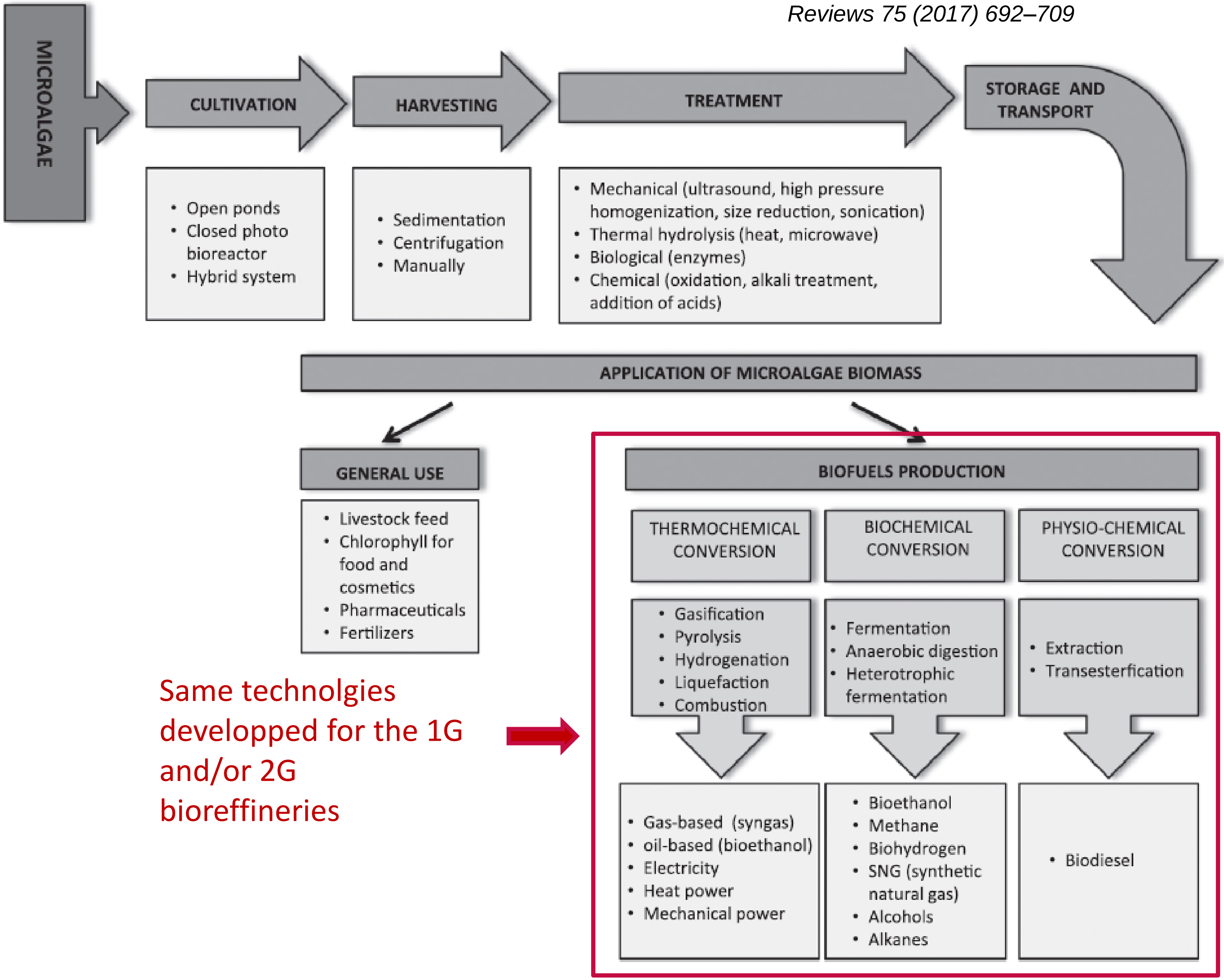


Fig. 3. Indigenous alga with high-value compounds. *Euglena cf. sanguinea* collected from a pond enriched by agricultural run-off. The photo, taken under brightfield transmission illumination, shows distinct regions of red carotenoids (presumably astaxanthin esters), green photosynthetic chlorophyll, and clear paramylon carbohydrate granules (storage material).

Affect the biochemical composition and therefore bioproduct potential of microalgae

A.C. Wilkie et al. 2011



Same technolgies developped for the 1G and/or 2G bioreffineries

Fig. 1. Microalgae process value chain.

Algal Cultivation Options

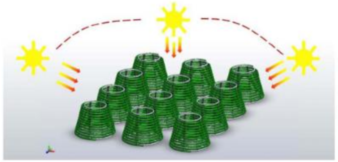
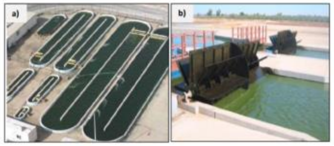
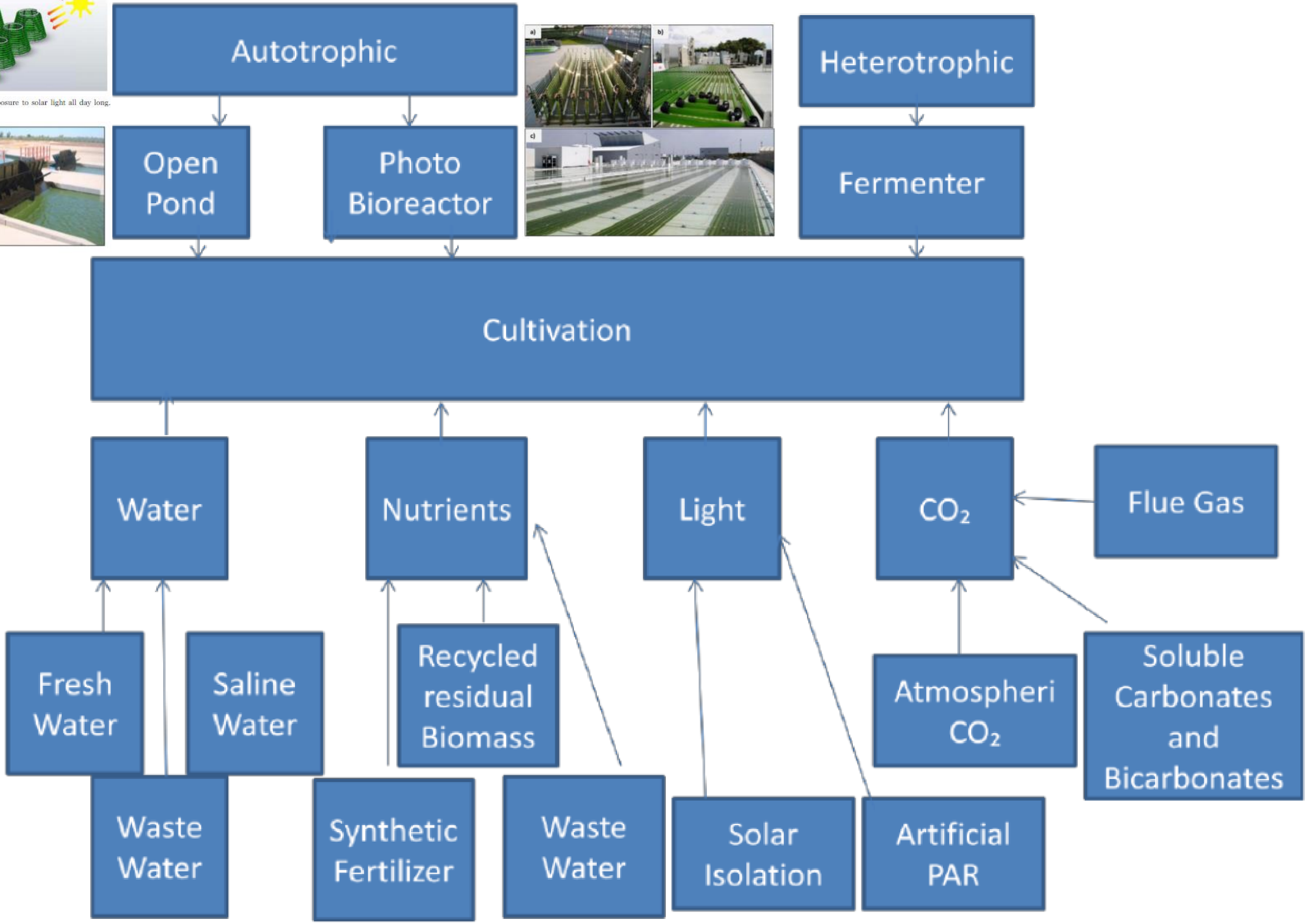
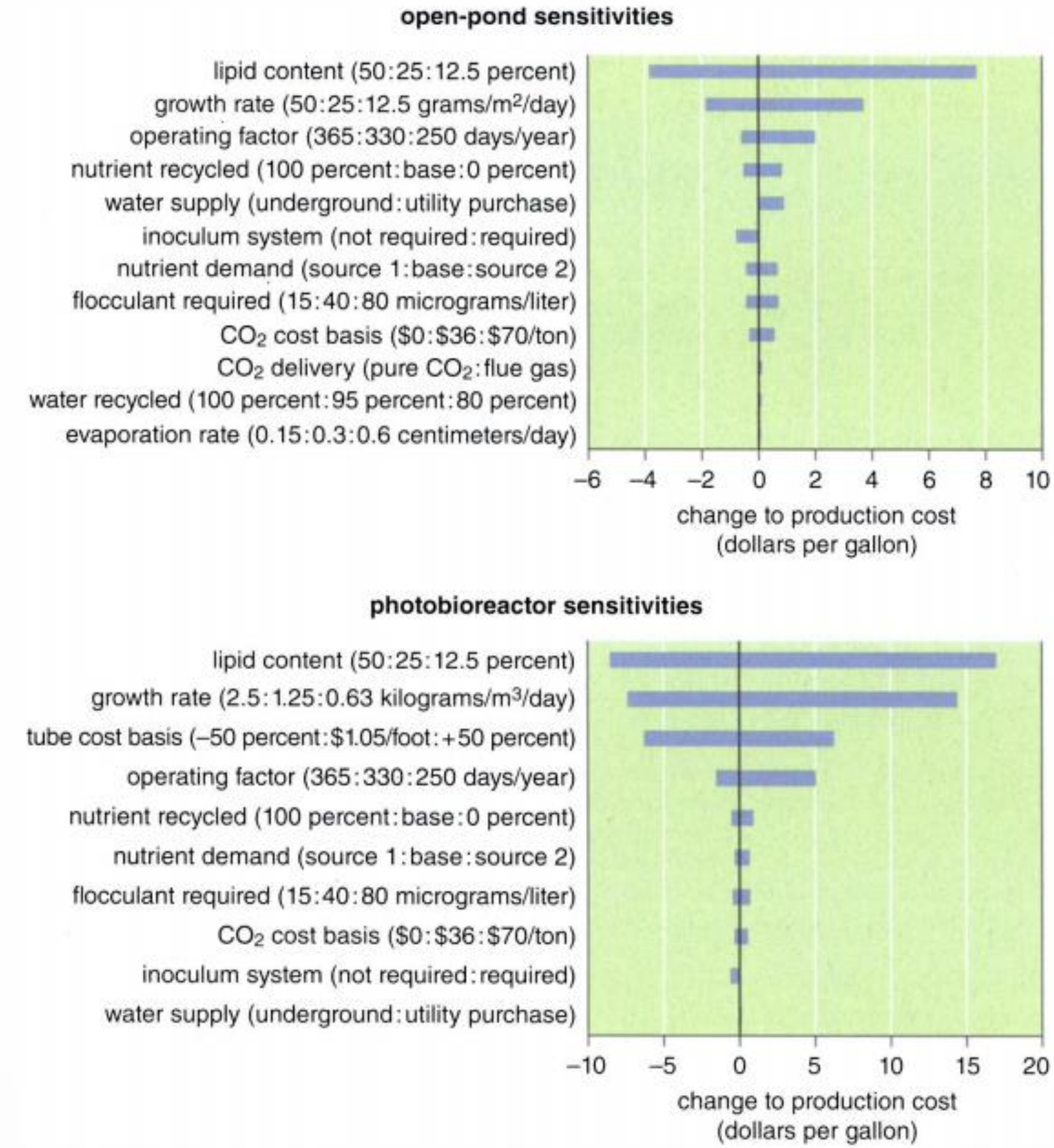


Fig. 1. The tree-like shaped PBRs allow for good exposure to solar light all day long. Source [42]: (© Gicon).



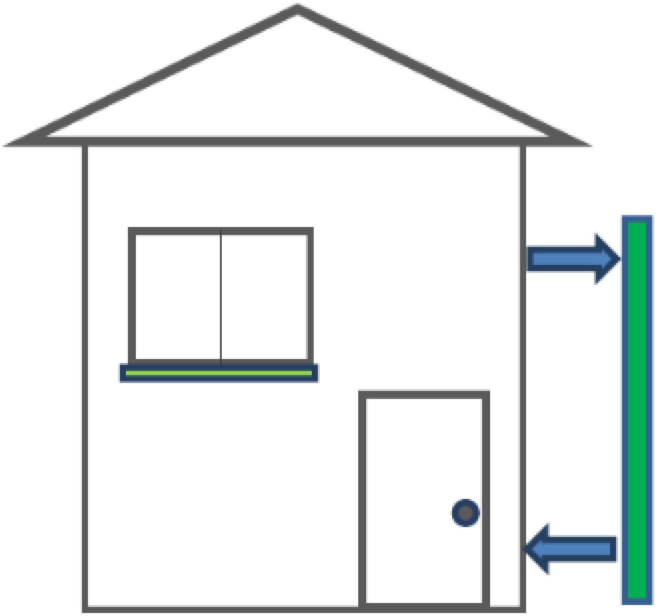




Sensitivity of algal fuel production costs to variations in production parameters

American Scientist, Vol. 99, No. 6 (November–December 2011), pp. 474-481

Intergration of PBR and microalgae cultivation in buildings



What to expect from an efficient photobioreactor building integration

Air quality: exchanging the inner air (CO_2) through the photo bioreactor will act as a bio-filter (by photosynthesis CO_2 will be used to produce O_2 by the microalgae cells)

Thermal comfort: The photobioreactor will act as a bio-curtain by blocking or reflecting the light (especially the dense cultures will be a strong light blocker)

Aesthetic design: A green façade will give extra attraction to a building

Principle design parameters of flat-panel PBRs for microalgae cultivation on façades.

Principle design parameters of PBRs	
Orientation	It depends on solar light intensity relevant to latitudes. However, it is noted that the southern orientation is common in previous studies
Thickness	It shouldn't be thicker than 5–6 cm.
Materials	Many types of glass and plastic (laminated safety glass, plexiglass, polyethylene film, transparent acrylic, transparent polycarbonate, and ETFE).
Temperature	It is advisable for zones with temperatures above 15 °C, which are located between 37° north and south latitudes. The optimal temperature is between 20–30 °C. Microalgae stop growing below 5 °C and above 35 °C.
Light intensity	The level of light intensity is critical because algae reach light saturation at a certain level and dissipate the excess heat. Light intensity can be enhanced by optical fibers and/or LED lights.
CO_2	Approx. 1.8 t of CO_2 are needed to grow 1 t of microalgae biomass. Factories oil refineries, flue gasses from power plants, and micro-combined heating and power (MCHP) can be used as sources for CO_2.
Nutrients	Nitrogen and phosphorus required for the cultivation system can be obtained from agricultural fertilizers, fish aquaculture, or wastewater (municipal wastewater, animal wastewater, industrial wastewater, and anaerobic digestion effluent)
Water	Any kind of water can be used, such as sea water and waste water. Approx. 0.75 l of water is needed per kg of algae biomass to produce one liter of biofuel.

General concept

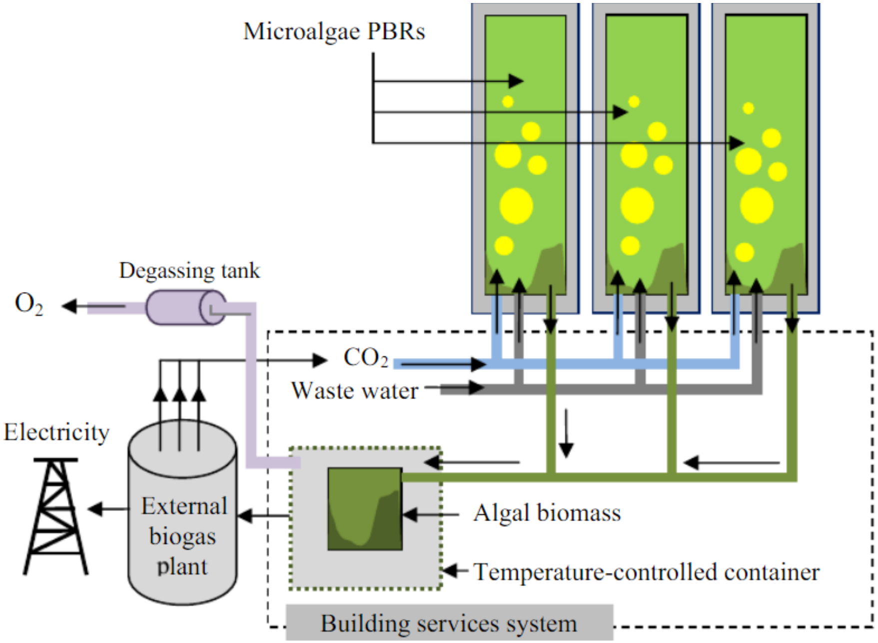
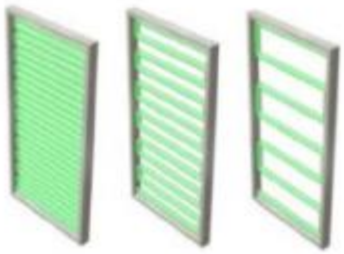


Table 4
A comparative analysis of the three selected building-integrated PBRs.
Source: adapted from [31,54,61,63,66,70–72].

Case study	Green Loop Tower, Chicago (41.8° N), Illinois	BIQ building, Hamburg (53.5°N), Germany	Process Zero, Los Angeles (34°N), California, USA
PBR Integration into Facade			
PBR Installation According to Building Type	Both new and retrofitted buildings.	Both new and retrofitted buildings.	Both new and retrofitted buildings.
PBR Orientation	The helical PBRs are wrapped around the entire perimeter of the cylinder-shaped building.	The flat-plate PBRs are installed on the southeast and southwest façades.	The tubular PBR panels cover the four building façades.
PBR Specification	A modular system of algal tubes is coiled around the CO_2 scrubbing units in a helical manner on the tops of both towers. In addition to the semicircular algal tubes those are installed in the first 18 floors (around the parking ramp of the east tower).	In total, 129 PBRs are installed on the southeast and southwest facades. Each PBR panel measures 2.5 m x 0.7 m with a thickness of 0.8 m. It has a capacity of 24 liters of liquid for algae growth. PBR is clad on both sides with laminated safety glass for safety and thermal insulation.	The PBRs cover 25,000 ft^2 of the GSA building's envelope with a modular network of transparent glass tubing PBRs. PBRs are part of a full-scale closed system of holding tanks and filtration ponds to complete the bio-energy network.
Microalgae PBR Design	 **Helical tubes PBR**	 **Flat vertical panel PBR**	 **Tube-panel PBR**

Case study	Green Loop Tower, Chicago (41.8° N), Illinois	BIQ building, Hamburg (53.5°N), Germany	Process Zero, Los Angeles (34°N), California, USA
PBR Integration into Facade			
PBR Installation According to Building Type	Both new and retrofitted buildings.	Both new and retrofitted buildings.	Both new and retrofitted buildings.
Source of CO_2	From CO_2 scrubbing plant based on the humidity swing technique positioned on the tops of the two towers. Air is captured by a wind turbine and then harvested and released by the CO_2 scrubbing unit to feed the algae PBR.	From flue gas of a biogas-fueled microCHP on site. A membrane technology and a saturation device are used to provide the water circuit with a CO_2 stream. Then the CO_2 is dissolved and circulated to the PBRs together with the nutrients and water.	The system derives its CO_2 from the nearby Santa Ana Freeway on site.
Source of Water and Nutrients	Waste water of Marina City inhabitants. All waste water is processed to be reused either in the WCs of Marina city or to irrigate vertical farming.	The culture medium enriched with nitrogen, phosphorus, and trace elements as nutrients.[a]	Waste water of the building is the source of water. The black water of the building is processed to be a source of nutrients.
Building Services System Location	NA[b]	Under the building subsoil.	NA[b]

[a] No documented information about the source of nutrients
[b] No documented information about the building services system location

Table 6
The basic inputs and outputs of the building's bio-façade and the technical requirements.

No.		Inputs	Technical requirements
1)	Carbon dioxide	**Flue gases from power plants, factories, high ways, etc.** If there is no adjacent source of CO_2, the capture of CO_2 for algae cultivation will be limited. So it is imperative to consider a reasonable geographic proximity of stationary sources or to provide a CO_2source as an integral part of the building [91]. Systems attached to the buildings, such as the CO_2 scrubbing system solve the problem of transporting and storing CO_2. In the CO_2 scrubbing system, a source of electricity is required for the operation. So, an integrated wind turbine can operate the system in a sustainable way.	1. Geographic proximity to CO_2 sources and/or 2. CO_2 scrubbing system.
2)	Water	**Any kind of water** Microalgae can bloom in any type of water (sources of water not suitable for consumption). The resulting water can be reused again as reclaimed water, making a closed-loop of the water path within the PBR.	1. Sea water; 2. Rainwater; 3. Saltwater; 4. Brackish; 5. Polluted or wastewater
3)	Nutrients	**Building's gray and black water** Nutrients can be obtained from the building's liquid wastes, from gray and/or black water.	1. Nutrient separation system
4)	Microalgae	After harvesting microalgae, it is important to store it in temperature-controlled containers until the conversion process. The conversion process can be operated on the building's service system, or the microalgae can be transported outside the site to be converted into oil, electricity, or other products.	1. Temperature-controlled container
		Outputs	
5)	Heat	As the PBR façade acts as a thermal insulator, it converts solar light into heat. The resulting heat participates with a considerable percent of the produced energy. Heat needs to be extracted by a heat exchanger to be used in the building's heating purposes. The excess heat can be stored in geothermal boreholes for future use, or it can be sold to the district heating network.	1. Heat exchangers 2. Geothermal boreholes
6)	Algal biomass	A filtration system, as centrifuge equipment, is required for extracting the green products. Oil from algae is used for biofuel production, algal biomass is used to generate electricity when converted to methane by an external biogas plant, and reclaimed water is reused for the culture.	1. Centrifuge 2. External biogas plant
7)	Oxygen	In flat-plate PBRs , a gas-liquid interface is needed for the removal of oxygen gas [49]. A degassing column is required for O_2 removal [40].	1. Gas-liquid interface 2. Degassing column

Sustainable development of the biofuels (2G and 3G) included the concept of environmental biorefinery

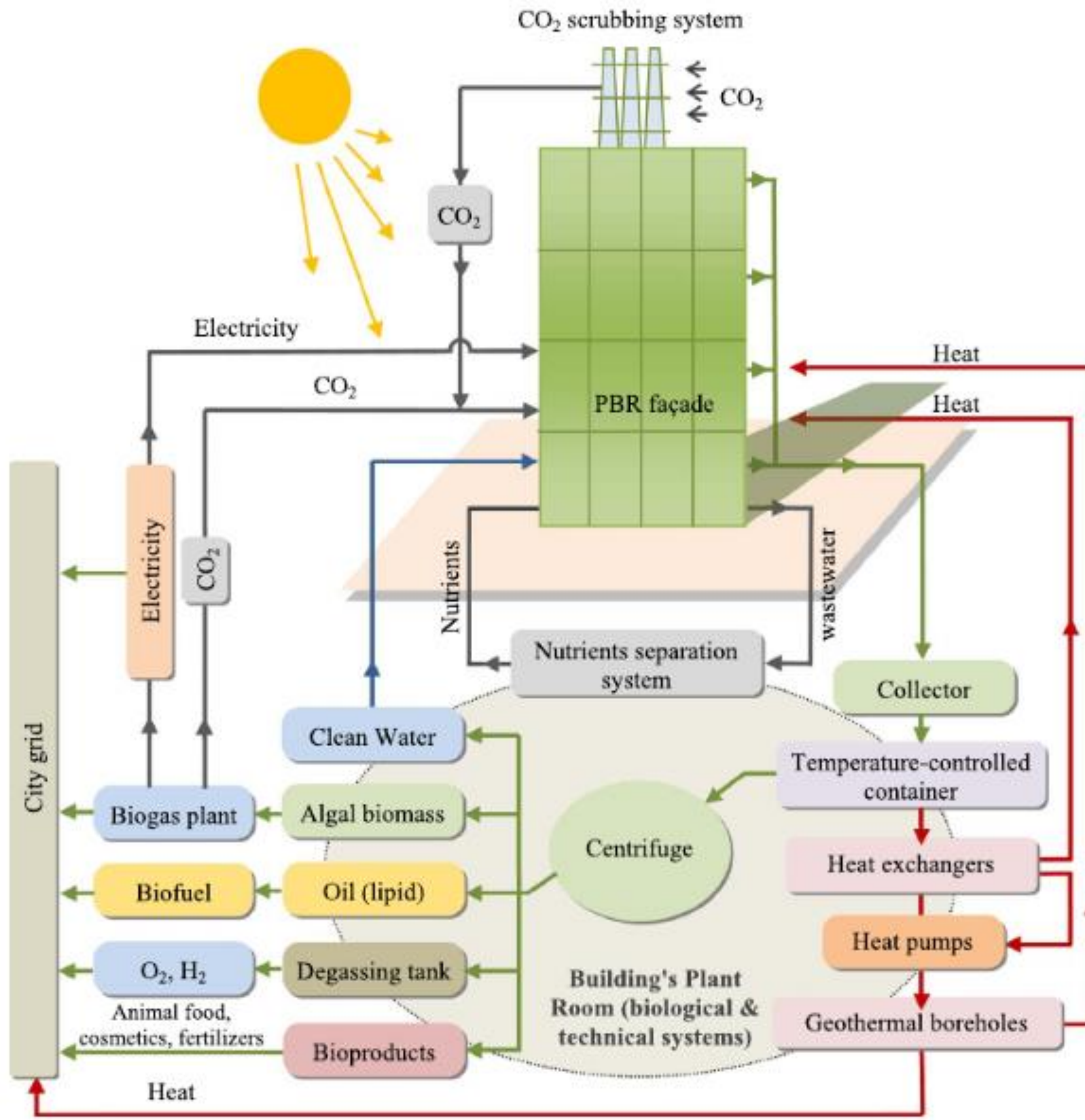
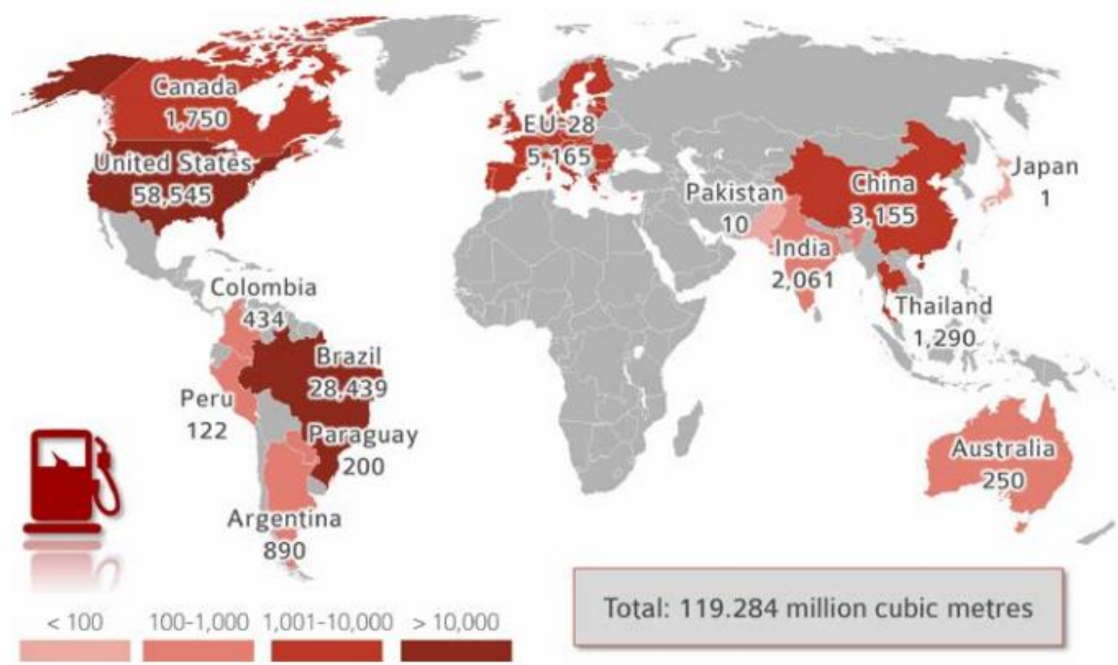


Fig. 9. Schematic concept of the holistic building's biorefinery infrastructure in building-integrated PBRs.

Conclusions

1G Biofuels				
Feedstoocks	**Current Technologies**	**Energy Products**	**Advantages**	**Disadvantages**
Rapeseed, soybean, palm oil, jatropha, vegetable oil, corn, sugarcane, sugar beets, cereals, cassava, maize	Transesterification, fermentation, and hydrolysis	Biodiesel, bioethanol	• Reduction in use of fossil fuels • Renewable sources	• Significant carbon missions • Impacts associated with fertilizers use • Large requirements of fertile land and water • Dilemma regarding competition with food

2G Biofuels				
Feedstoocks	**Current Technologies**	**Energy Products**	**Advantages**	**Disadvantages**
Lignocellulosic biomass such as wheat straw, corn stover, wood and special energy crop	Hydrolysis to fermentation, and Gasification to Fisher-Tropsch	Biodiesel, bioethanol, biohydrogen, biomethane, bio-DME, biobutanol, mixed alcohols, and hydrocarbons	• No competition with food • Reduction of fossil fuel use • Renewable sources • If waste cellulose is used, impacts associated with fertilizers consumption and land requirement could be reduced • A wide variety of potential energy products and coproducts can be obtained (biorefinery)	• Availability at large scale is a concern • Still in demonstration step • Limitation and consequences for large-scale production are not yet know

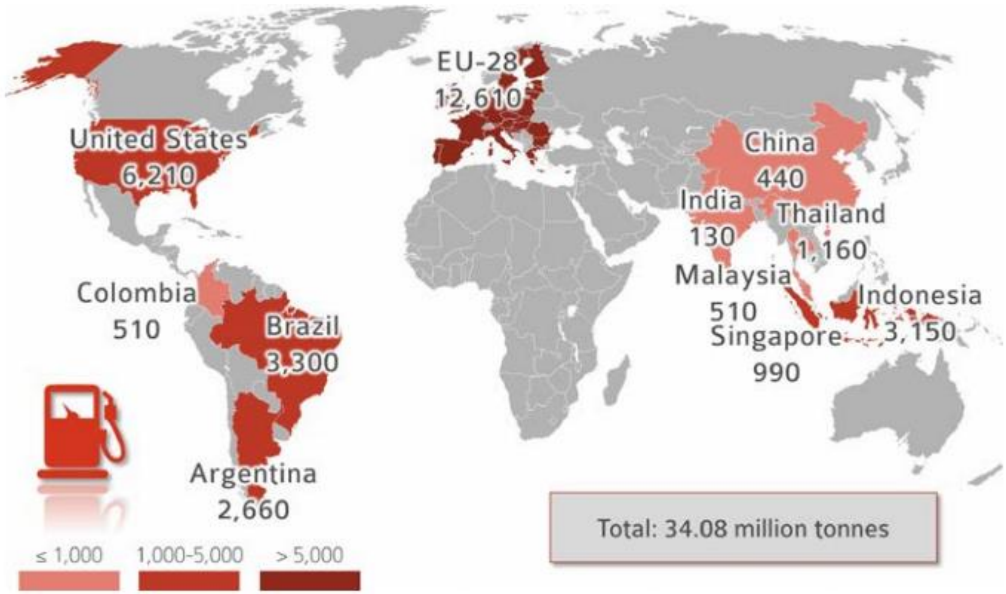


Bioethanol production in key contries in 2016 (in 1,000 m³)

© AMI 2017
Sources: National Statistics, OECD, FAS

Biodiesel production in key contries in 2016 (in 1.000 tonnes)

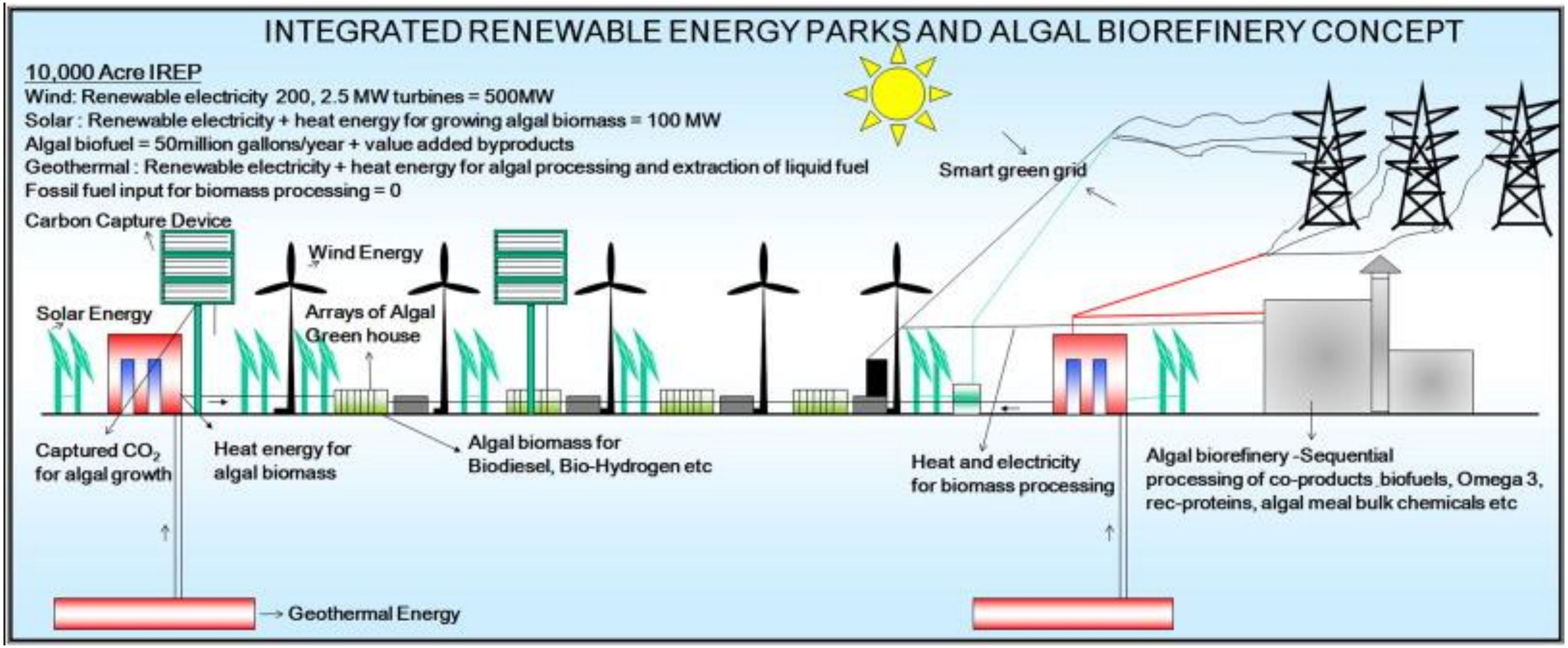
© AMI 2017 | Source: Oil World

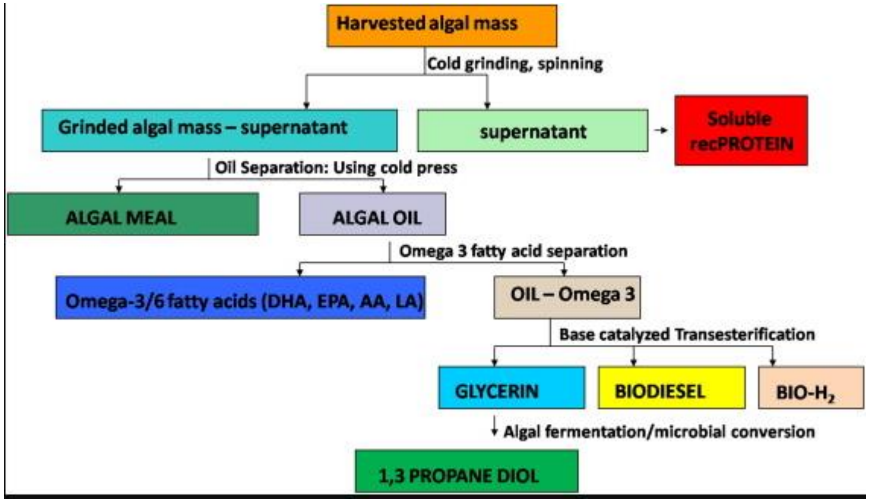


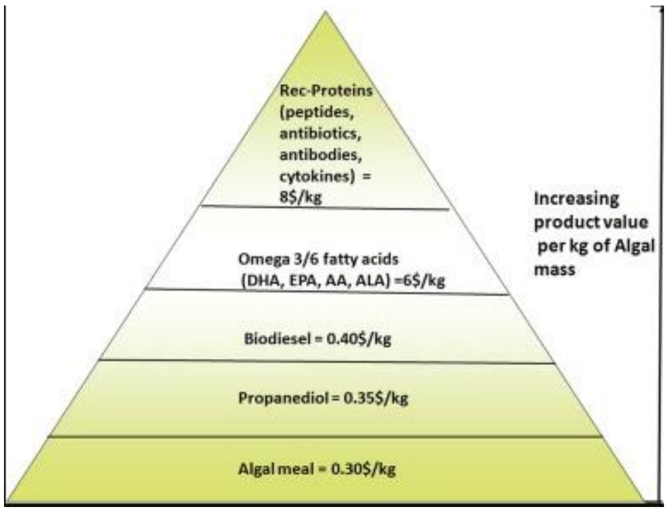
Conclusions

3G Biofuels				
Feedstoocks	**Current Technologies**	**Energy Products**	**Advantages**	**Diadvantages**
Micro and macroalgae	Transesterification, fermentation, anaerobic digestion, gasification	Biodiesel, bioethanol, biohydrogen, biomethane, bio-DME, mixed alcohols, biogas and hydrocarbons	• No competition with food • Biomitigation of CO_2 • Reduction of fossil fuel use • Non exigent cultivation characteristics • No requirements of fertoile land • Potential usage of waste stream in the process • High growth rate and lipid content • Renewable sources • A wide variety of potentiel energy products and coproducts can be obtained (biorefinery)	• Still under research • Large environmental impacts with power consumption during harvesting and extraction step

Integrated renewable energy park (IREP) approach







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Thank for your attention

Process Zero, Los Angeles (34°N), California, USA

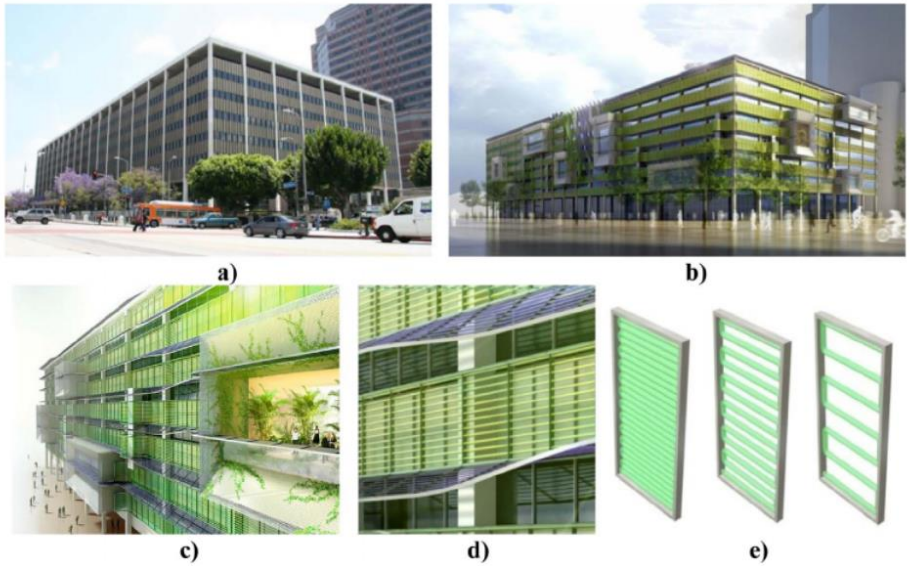


Fig. 7. a) GSA office building before retrofitting, b),c) the Process Zero retrofit of GSA; d), e) the tubular setup of the retrofit solution panelized grid (microalgae membrane). *Source* [73]: (© HOK /Vanderweil).

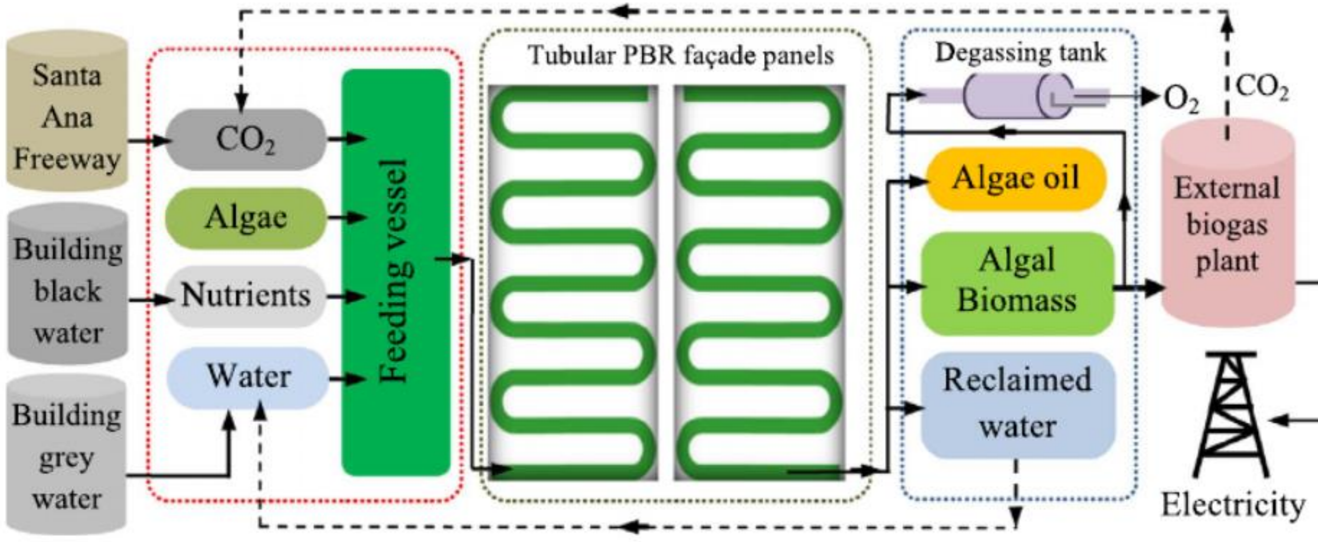
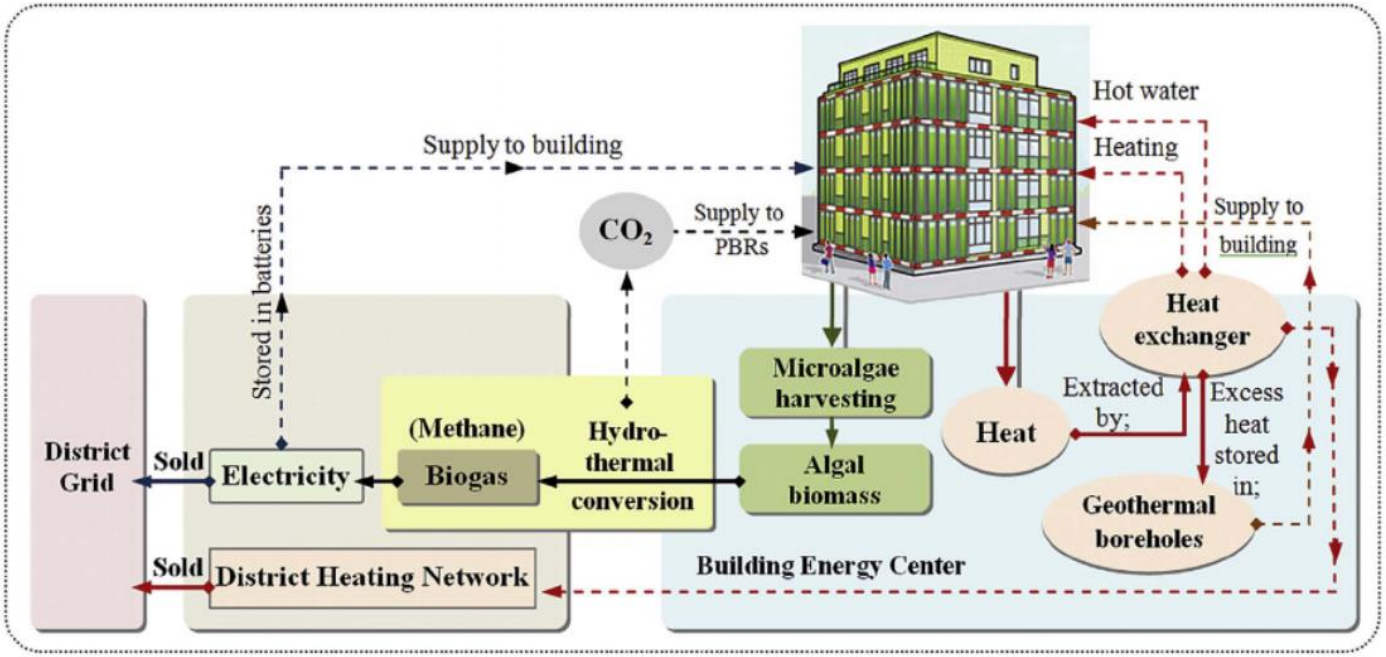


Fig. 8. Schematic concept of the microalgae photobioreactor system of the Process Zero Retrofit building. *Source:* drawn by the author from [72].

BIQ buidings
Hamburg
(51.3°N)
Germany



a) b) c)

Fig. 3. *The BIQ building*, the first *algae-powered building by Arup* (© Colt International, Arup Deutschland, SSC GmbH). *Source:* a) [65]; b), c) [60].

Green Loop Tower, Chicago (41.8°N), Illinois USA

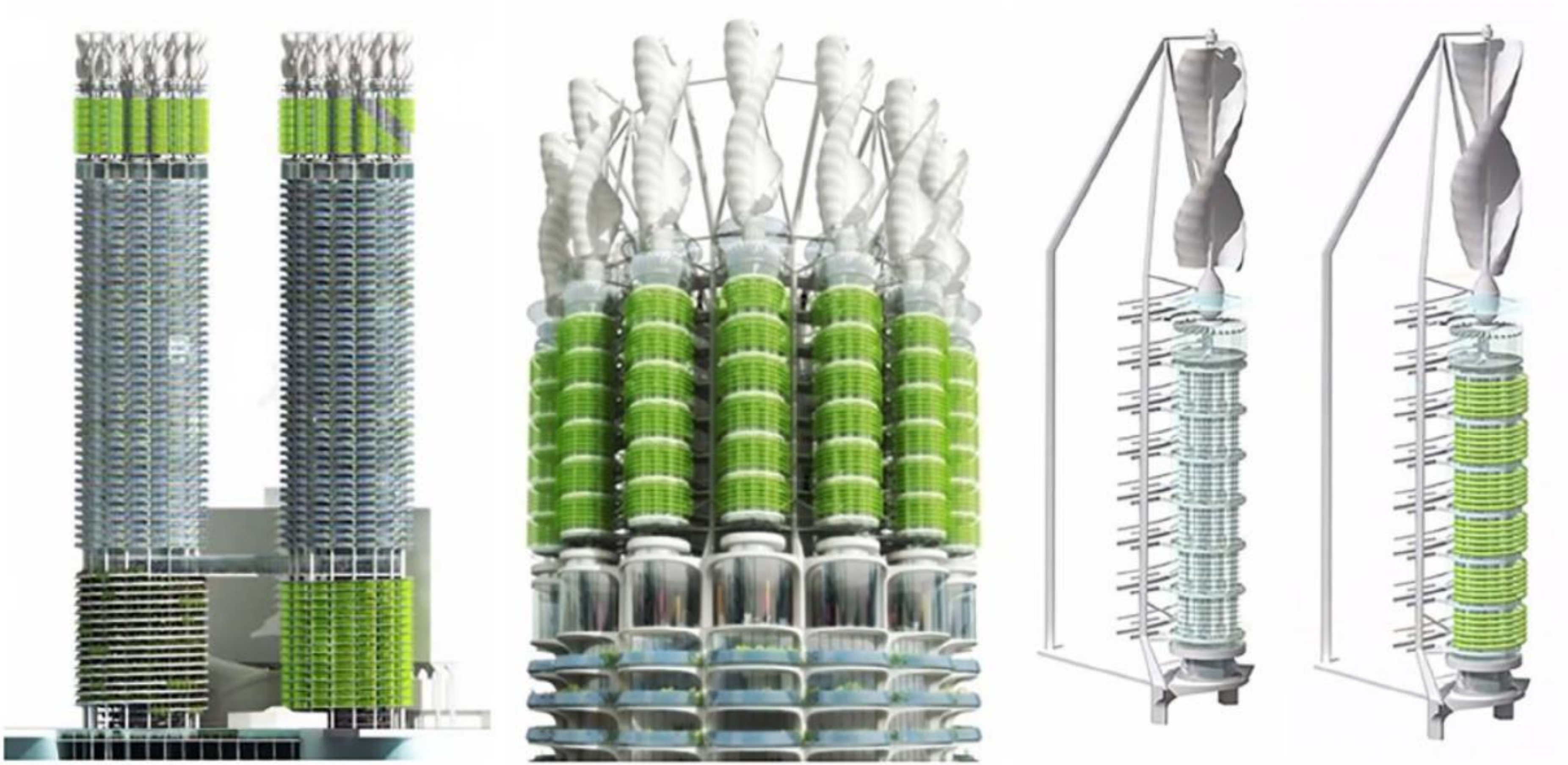


Fig. 6. a) The Marina City towers; b) carbon scrubbing plant; and c) The "humidity swing" captures CO_2 from air. Images permission from the designer, Mario Caceres
Source: [70].