

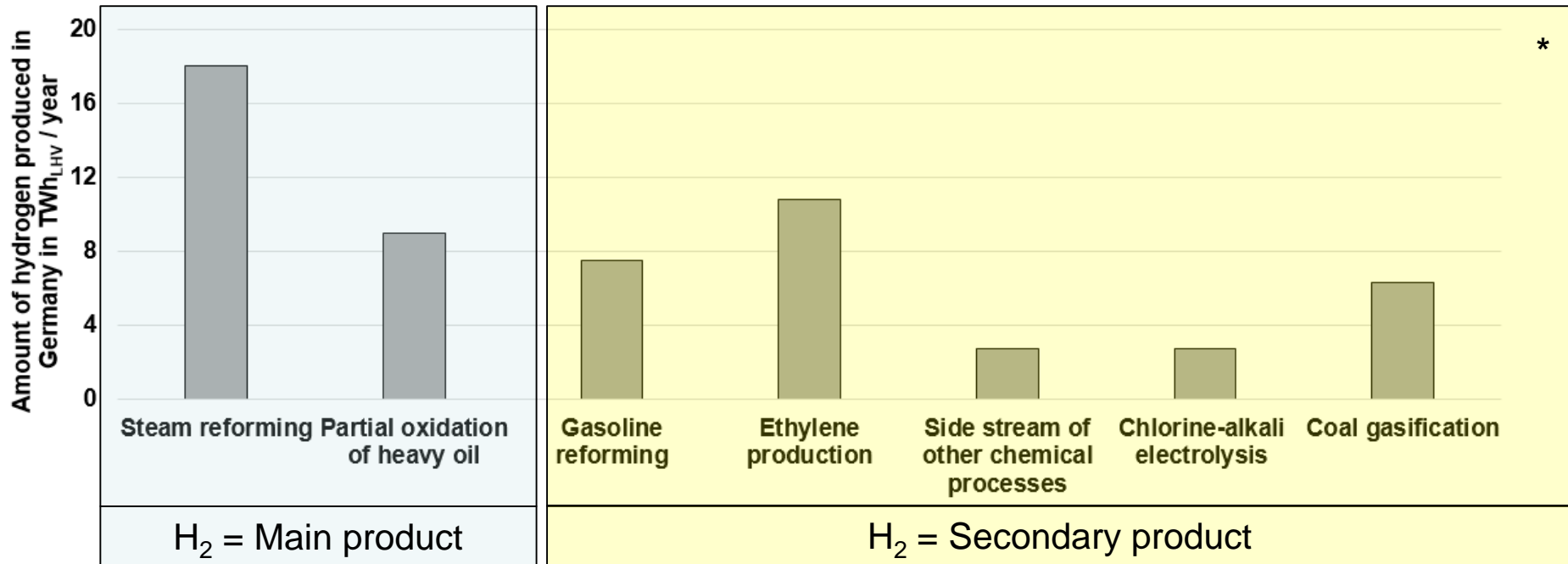


**Springschool Hydrogen Technology 2023**  
**(March 27-31, 2023)**

**Dark fermentative hydrogen production**  
—  
**potentials and opportunities**

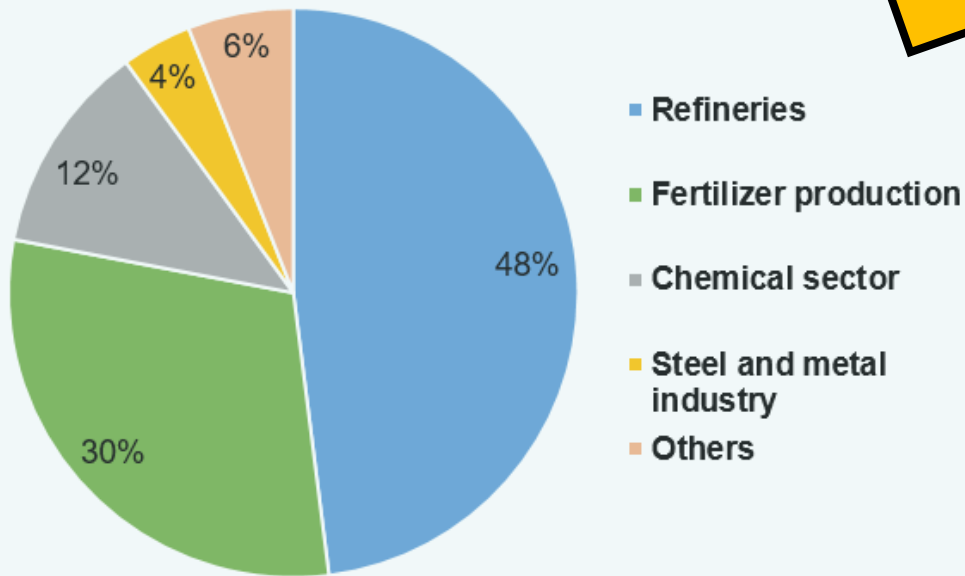
**Marvin Scherzinger**

- Hydrogen – Status quo
- Options to produce climate neutral hydrogen
- Hydrogen production from biomass
- Concept of dark fermentation
- Embedding dark fermentation into the biorefinery sector
- Conclusion



- So far, the majority of the hydrogen produced is a by-product of other processes.
- Most of the hydrogen produced to date comes from fossil sources and is accordingly accompanied by the release of climate-impacting emissions.

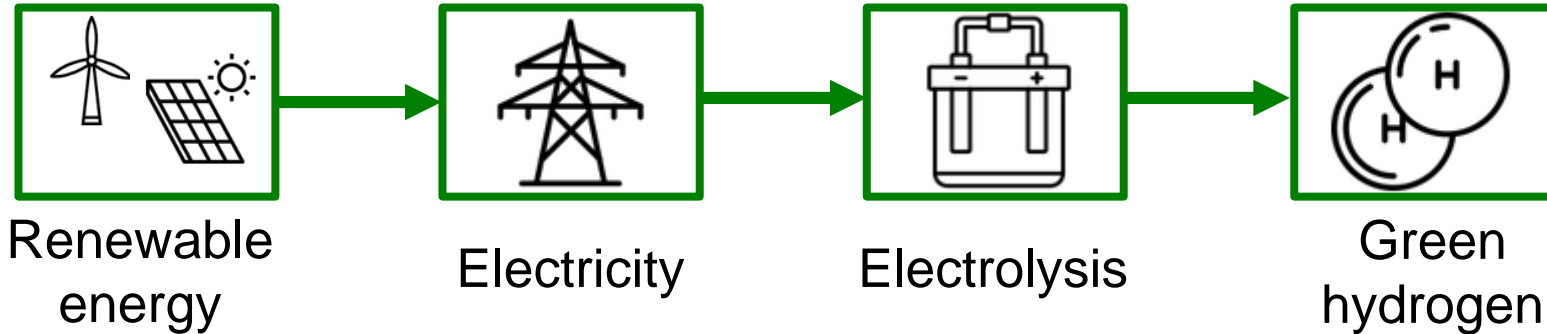
Current use of hydrogen in Europe \*



Strategic future markets  
(according to the national  
hydrogen strategy 2020)

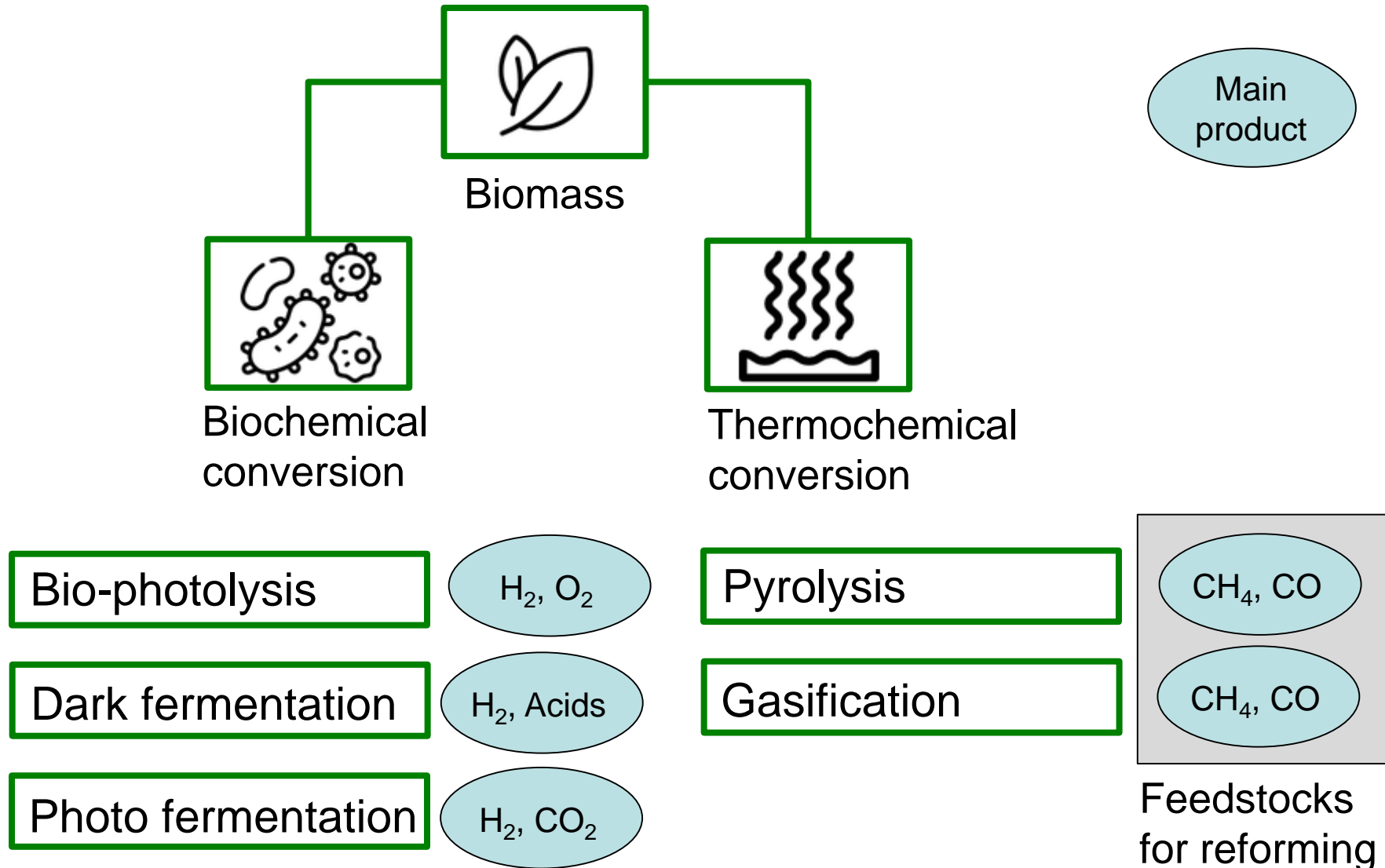
- Industry
- Mobility
- Heat

- It is assumed that the demand of hydrogen will increase sharply in the next years.
- This is only compatible with climate protection targets if hydrogen production will be fossil-free.



- The production pathway shown is not the only way to produce hydrogen from renewable sources.
- Since renewable electricity is limited and hydrogen production based on electrolysis faces numerous challenges, the hydrogen production from biomass could play a supporting role.

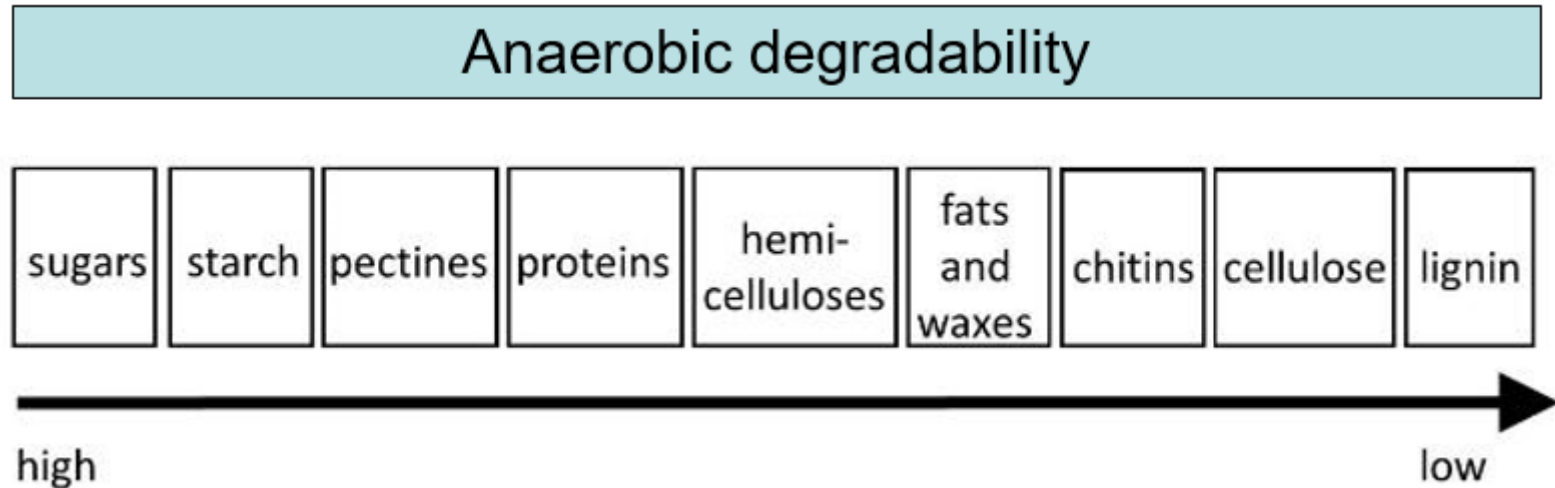
# Hydrogen production from biomass




## Definition of the term „biomass“

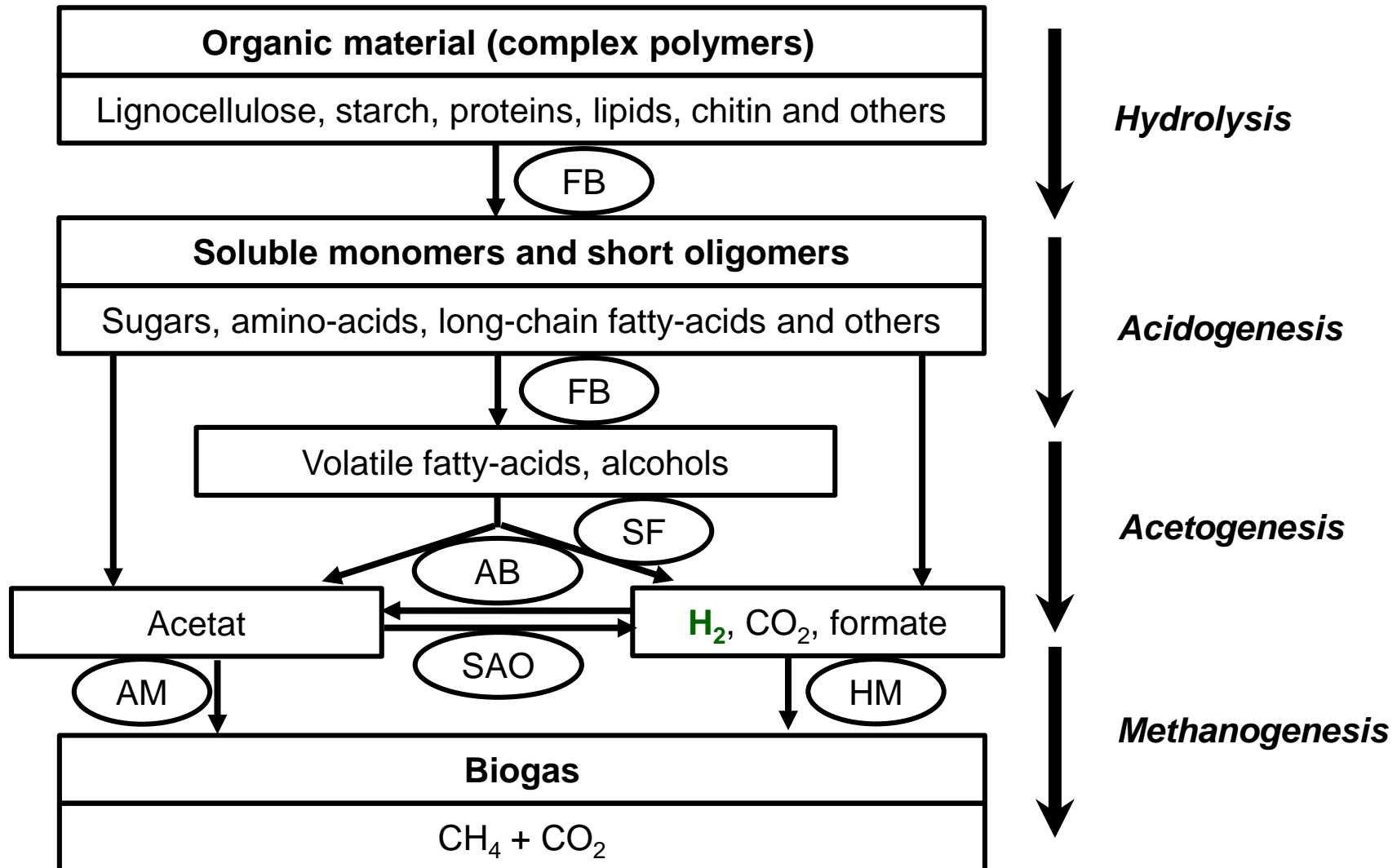
All substances of organic origin (i.e. carbonaceous matter)

- the phyto and zoomass (plants and animal) living in nature
- the resulting residues (e.g. animal excrements)
- dead (but not yet fossil) phyto and zoomass (e.g. straw)
- in a broader sense, all substances that are produced by a technical transformation and / or material use (e.g. organic household waste)



- 
- Not all types of biomass are suitable as substrates for dark fermentation (e.g. lignin cannot be degraded anaerobically).
  - The content of organic substance should be appropriate for the selected fermentation process and its technical properties.
  - The conditions occurring in the process are also largely due to the chosen substrate.

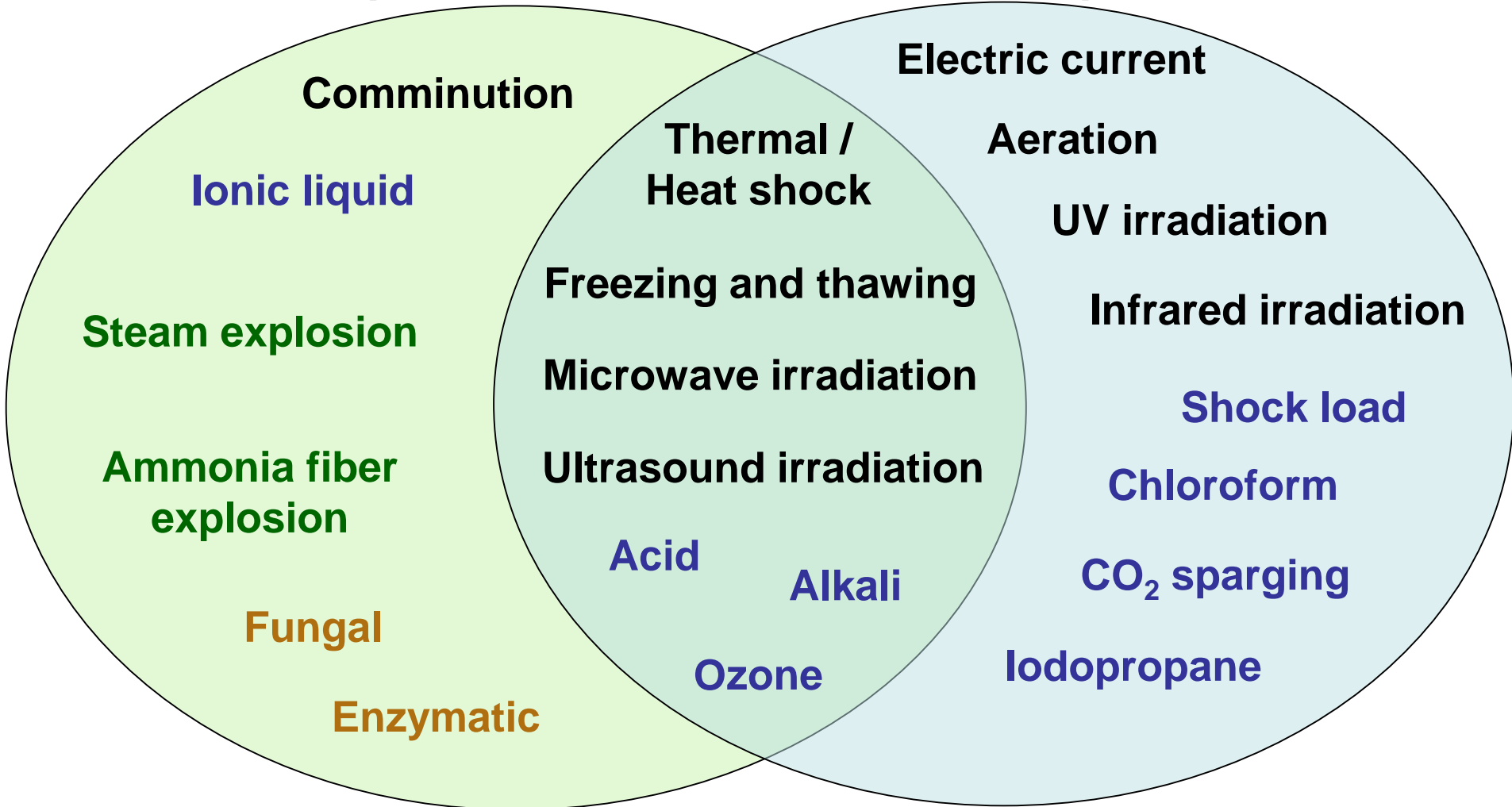
# Connection between anaerobic digestion and dark fermentation



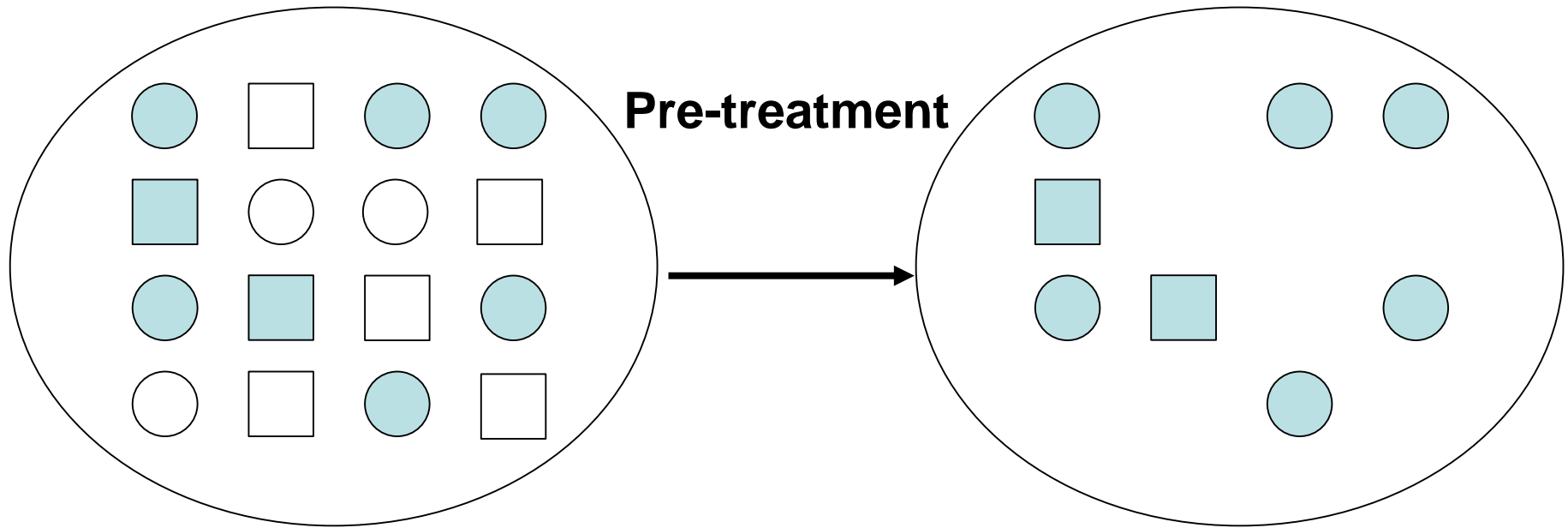
	Pure cultures (e. g. <i>Clostridium</i> sp.)	Mixed cultures (e. g. anaerobic sludge)
Pros	<ul style="list-style-type: none"><li>• Easy detection of metabolic shifts due to the low diversity of microbial biomass</li><li>• Relatively high H<sub>2</sub> yields</li></ul>	<ul style="list-style-type: none"><li>• Relatively simple in terms of process control and operation</li><li>• Applicable to a large number of different substrates</li><li>• No need for sterile conditions</li></ul>
Cons	<ul style="list-style-type: none"><li>• Not always feasible due to indigenous bacteria on the substrates</li><li>• Reduced hydrolytic degradation of substrates</li></ul>	<ul style="list-style-type: none"><li>• Presence of H<sub>2</sub> consuming microorganisms (e. g. methanogenic archaea)</li><li>• <b>Need for inoculum pre-treatment</b></li></ul>

## Substrate pre-treatment

## Inoculum pre-treatment \*



Physical, chemical, physicochemical, biological technologies

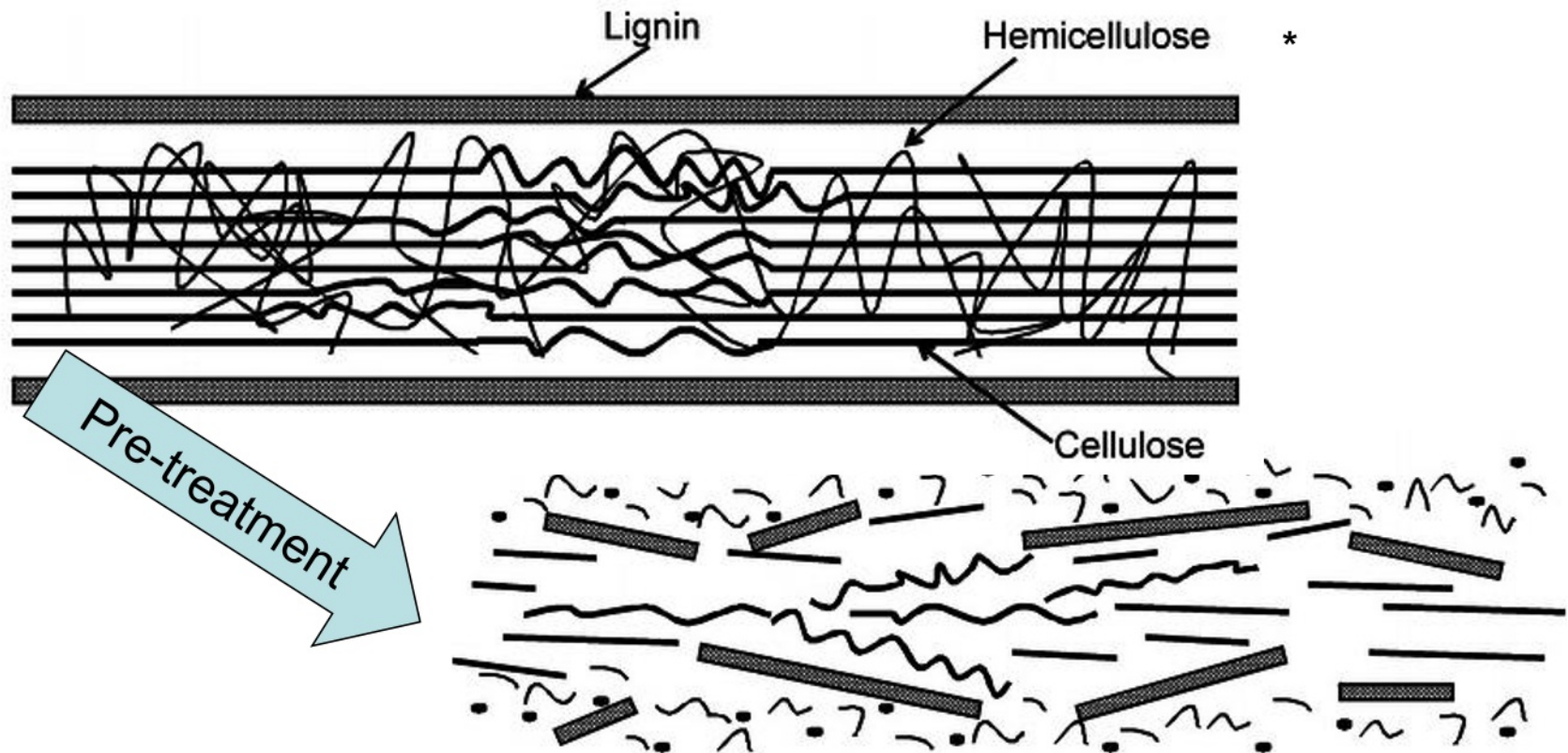


 Sporulating H<sub>2</sub>-producers

 Non-Sporulating H<sub>2</sub>-producers

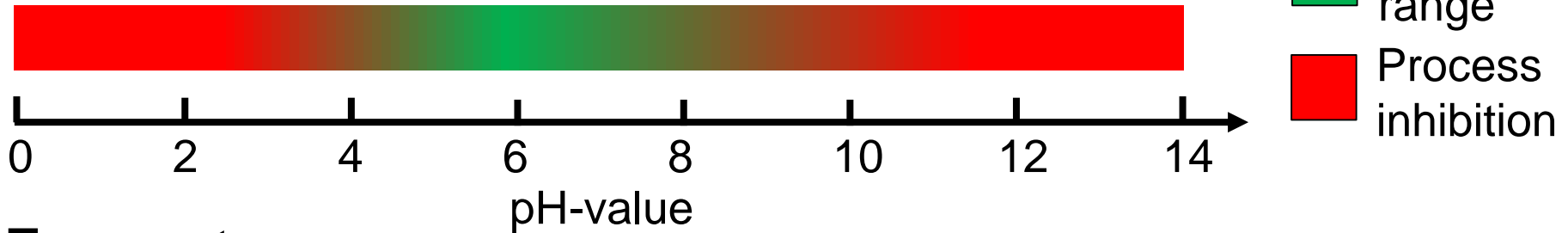
 Sporulating H<sub>2</sub>-consumers

 Non-Sporulating H<sub>2</sub>-consumers

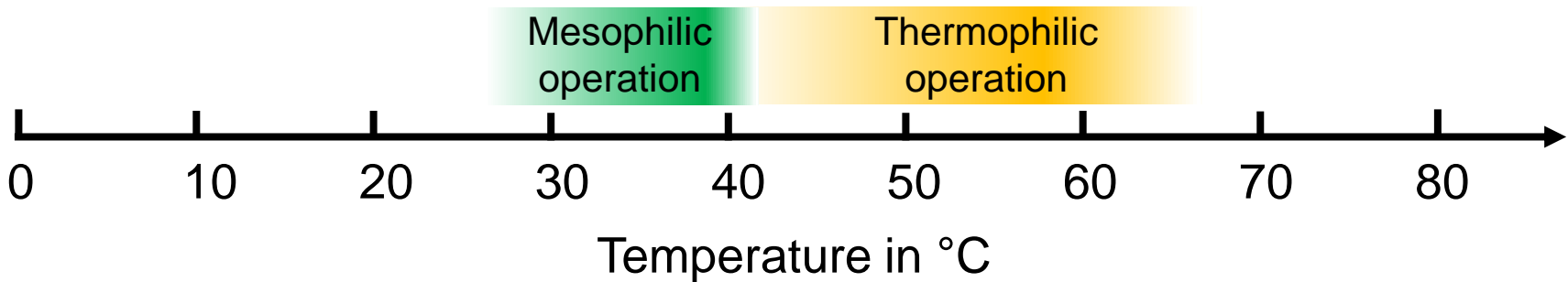


# Important parameters in dark fermentation

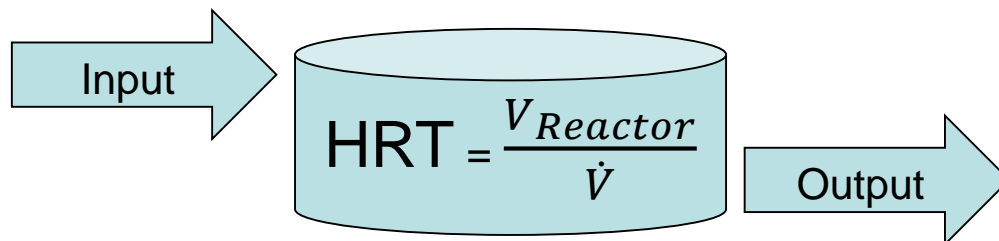
## pH-value



## Temperature



## Hydraulic retention time



Dark fermentation:  
HRT  $\leq$  24 h

Biogas production:  
HRT  $\geq$  24 h

# Potential substrates

## Agricultural substrates

Livestock farming



Energy crops



Herbal residues



## Industrial substrates

Meat processing



Fruit processing



Sugar industry



## Municipal substrates

Collected organic waste

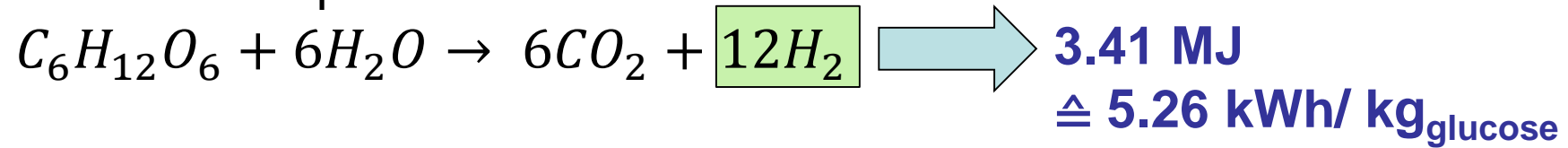


Landscape conservation



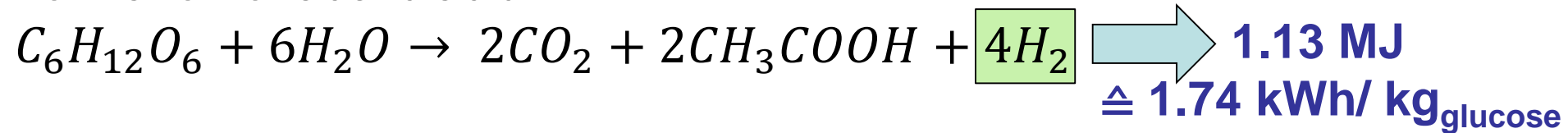
## Dark fermentation

Theoretical optimum:

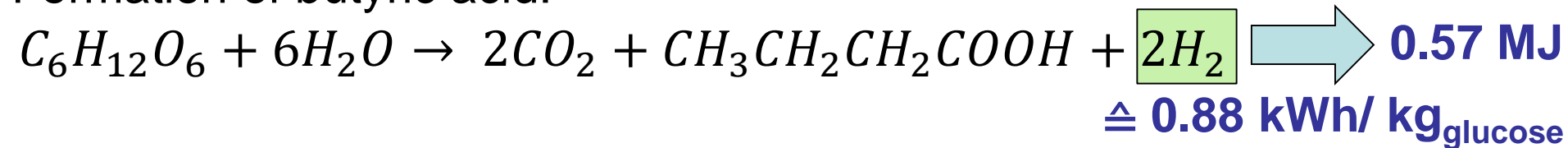


$H_2$   
Molar mass: 2 g / mole  
Energy value: 142 kJ / g

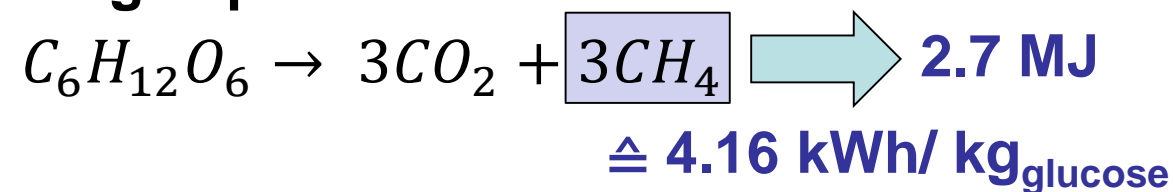
Formation of acetic acid:



Formation of butyric acid:



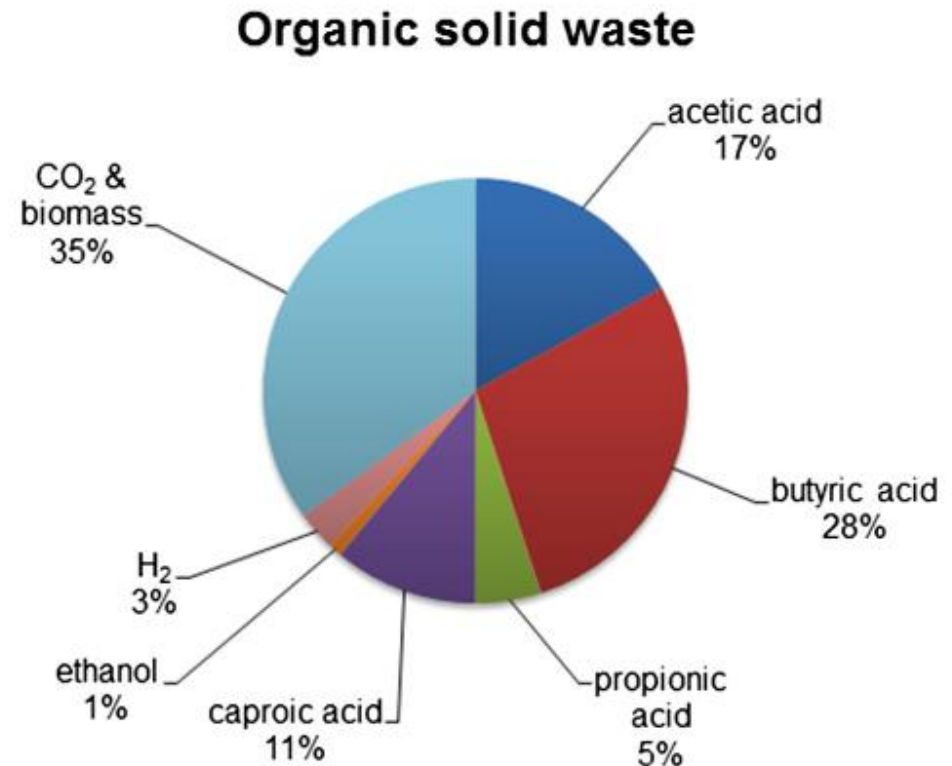
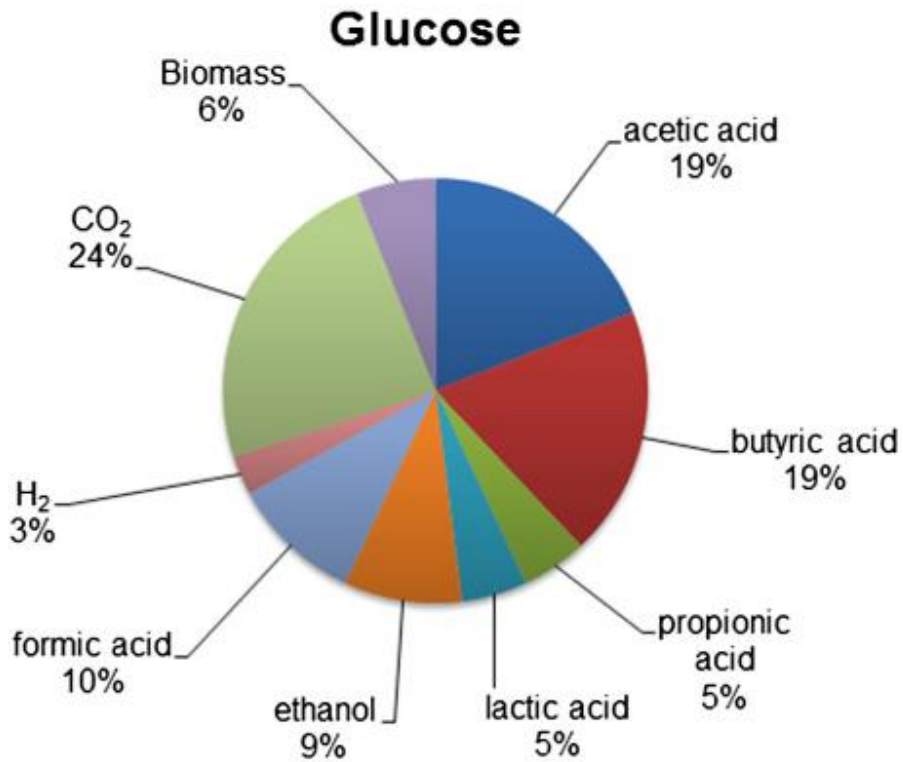
## Biogas production



$CH_4$   
Molar mass: 16 g / mole  
Energy value: 55.6 kJ / g

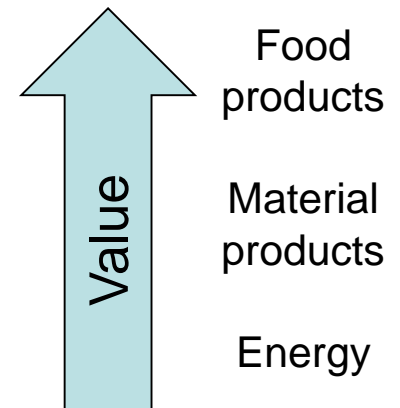
# Product distribution during dark fermentation

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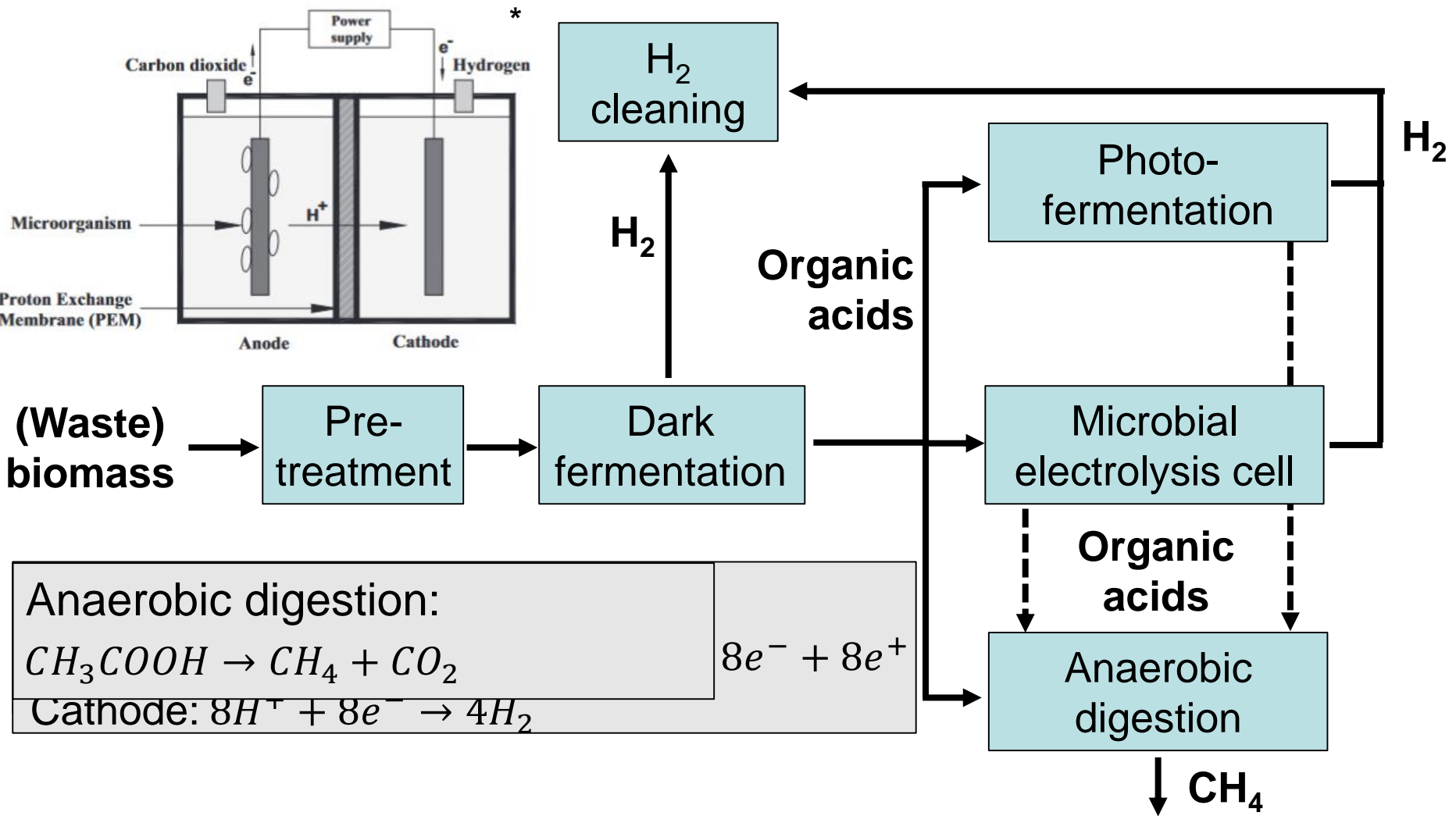


Yields are expressed as mass percentage of substrate consumed (i.e. glucose and organic solid waste)

- Only little parts of the used organic substrates are converted to  $H_2$  via dark fermentation, but significant amounts of other carbonaceous products emerge.
- It is expected that biogenic carbon will gain importance with increasing de-fossilization.
- Dark fermentation as a stand-alone option for hydrogen production therefore does not seem to be a viable concept, as the (valuable) carbon would be lost in the process.
- However, by coupling dark fermentation with other biobased processes as part of a biorefinery, it could gain relevance in the future.



# Concepts for dark fermentation

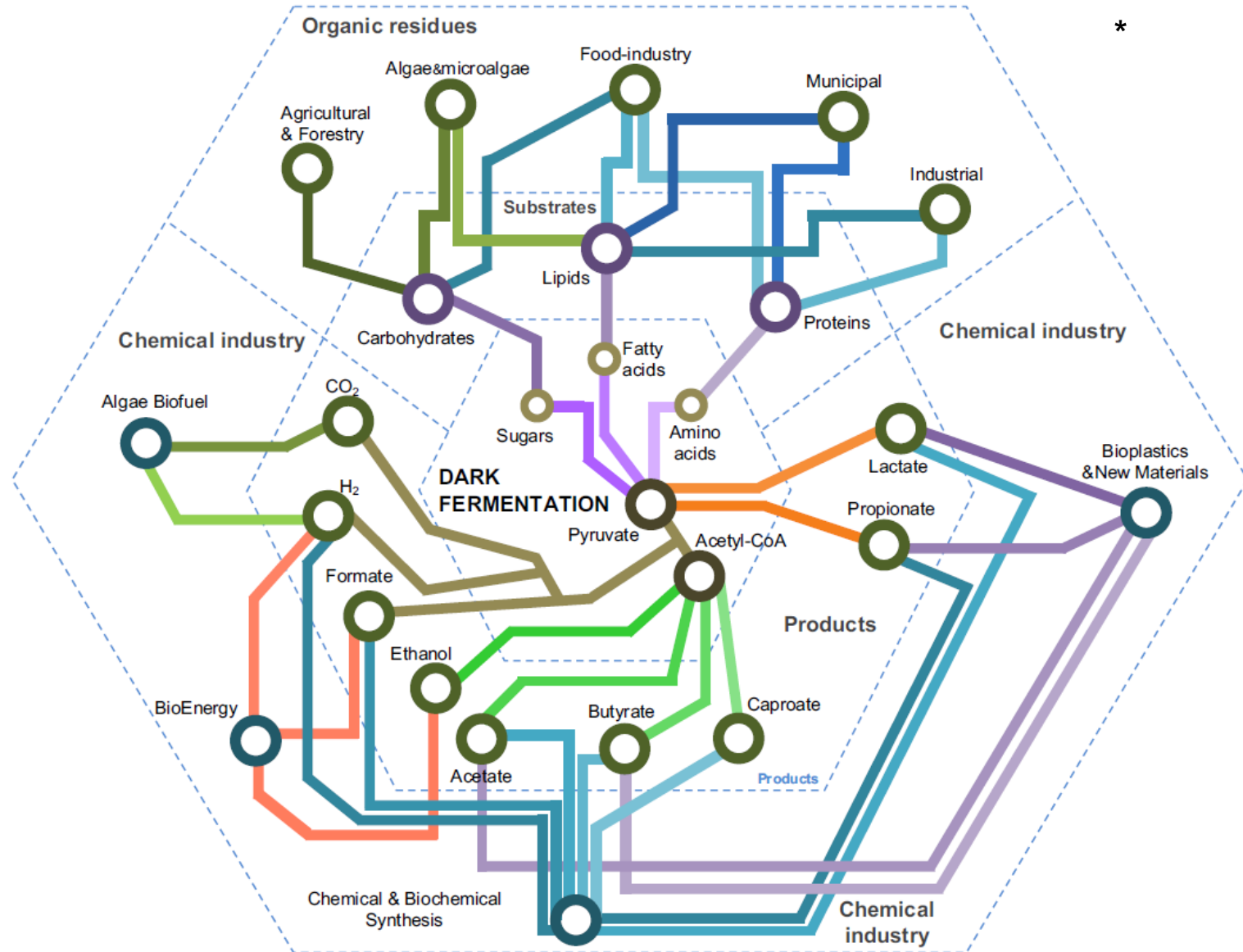


\* Ghimire et al. (2015), A review on dark fermentative biohydrogen production from organic biomass

## Remarks:

- The processes presented are not yet market ready (with the exception of anaerobic digestion).
- The integration of dark fermentation is relatively complex (e.g. due to the need for special expertise regarding the microorganisms involved, need for additional reactors, etc.).
- Economies of scale could compensate for the high costs, but there must be enough biomass at the plant's location for this to succeed (transport over long distances usually leads to high costs).
- By increasing the value of the products (e.g. use of the resulting acids in the chemical industry), the processes could be economically viable in some places.

# Classification in the biorefinery sector



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## Short term effects

- Formation of R&D cooperation
- Innovative technology development
- Mobilization of additional funds

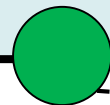
## Medium term effects

- Commercial exploitation
- Formation of strategic alliances
- Production increase
- Company growth

## Long term effects

- Broad industrial effects
- Economical effects
- Increasingly defossilized economy

Research and development projects



Present day

Time

- Hydrogen production from biomass via the dark fermentation route can be useful under certain conditions, but only if resulting co-products can be used.
- There are still questions about the classification of hydrogen produced in this way (so far it is not considered "green").
- In many areas, the process is too complex and thus will not be able to compete with other concepts (e. g. biogas production, hydrogen) in the long term.



Technische Universität Hamburg  
Institut für Umwelttechnik und Energiewirtschaft (IUE)  
Eissendorfer Str. 40; D-21073 Hamburg  
Dr. Marvin Scherzinger ([marvin.scherzinger@tuhh.de](mailto:marvin.scherzinger@tuhh.de))