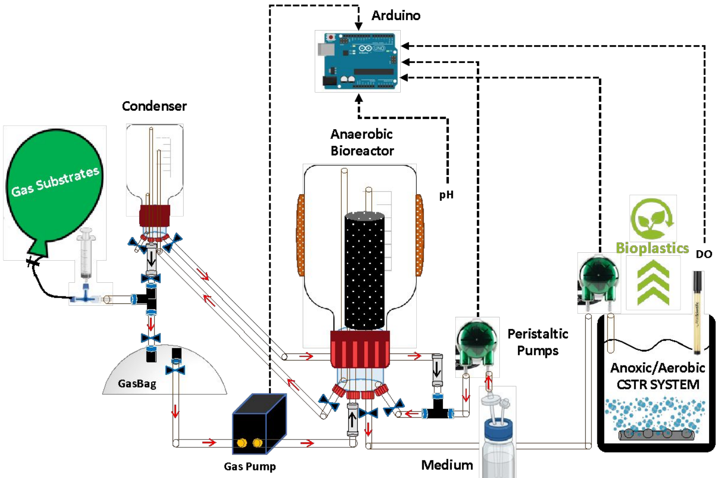
#Biomass-to-Material

#GasFermentation

#Biomaterials

#Biotechnology



#PHB

#Biochar

Inorganic Gasses into Organic Acids for Polyhydroxyalkanoates Production: An Integrated Lab-Scale System for the Syngas Fermentation Coupled PHA Production

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#Bioplastics

#Anaerobes

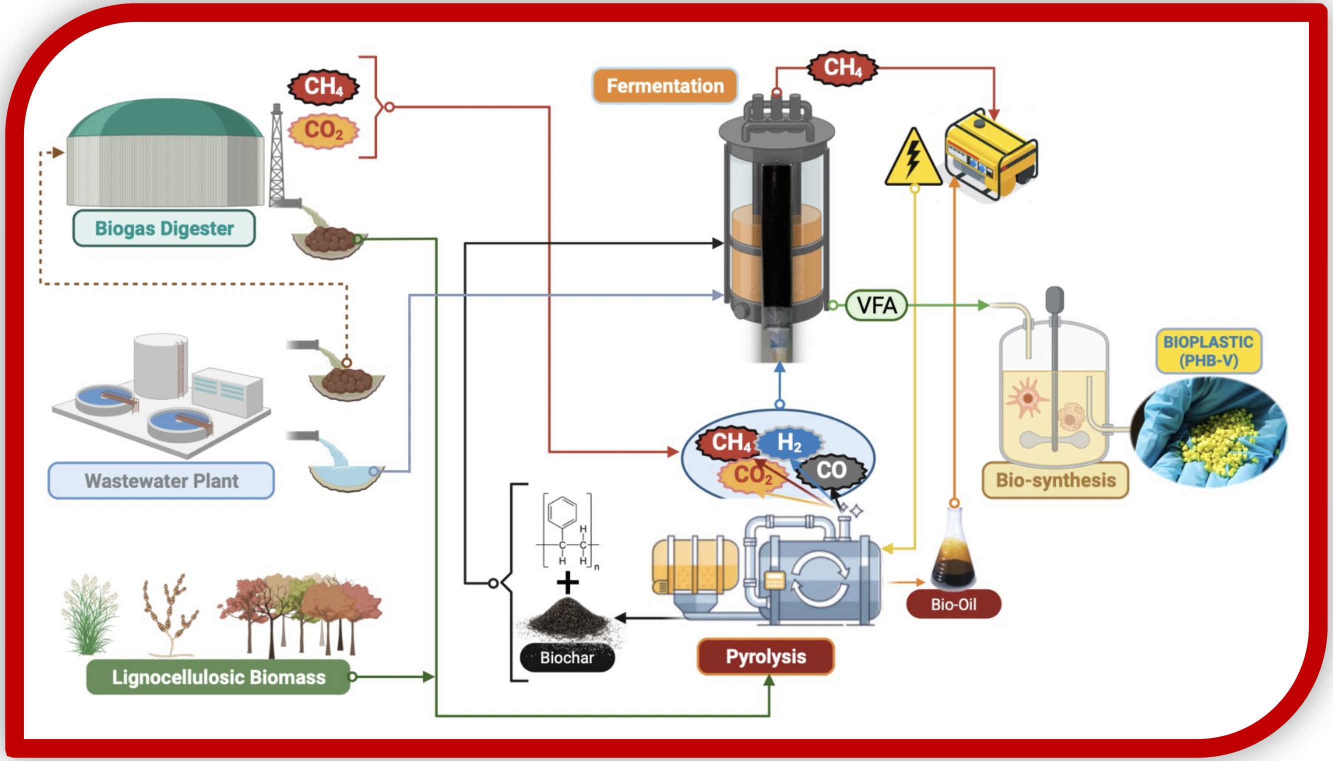
#GreenEconomy

#Gas-to-VFA

Proposed Approach

Hybrid Thermochemical-Biological Biorefinery

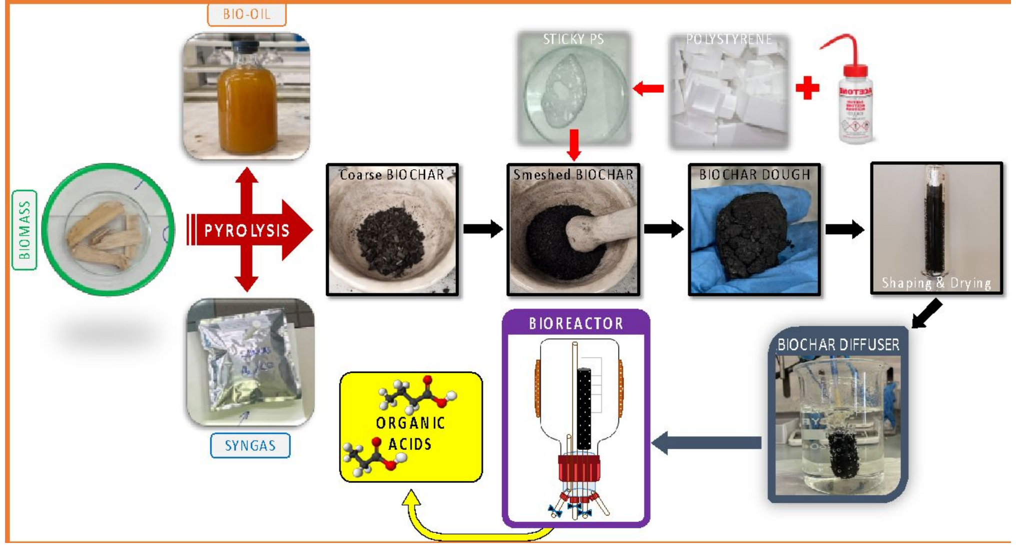
- Biomass materials (wooden and/or organic waste) can be thermally converted into C1 rich **syngas**, energy-rich **bio-oil**, and porous carbonous **biochar**.
- **Syngas** and **biochar** can be utilized by **syngas fermentation** technology which can convert C1 gasses and H_2 into the organic acids (VFA).
- Porous and conductive **biochar** material is proposed to enhance anaerobic conversion.
- **Bio-oil** as a liquid fuel and **CH_4** (Methane) as a gas fuel can be theoretically used to recover energy that is required for pyrolysis.
- N and P rich **wastewaters** can be used as nutrient source for both sequential biological systems (thanks to **MMC** technology).
- **PHA**s are the target final products as value-added biodegradable plastics.

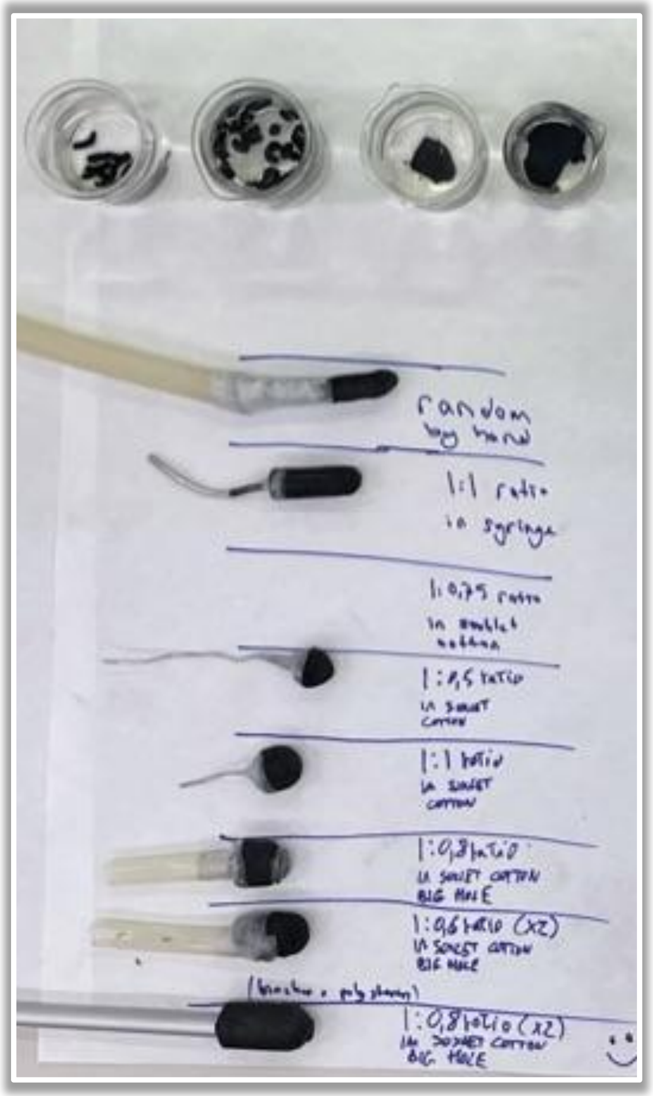


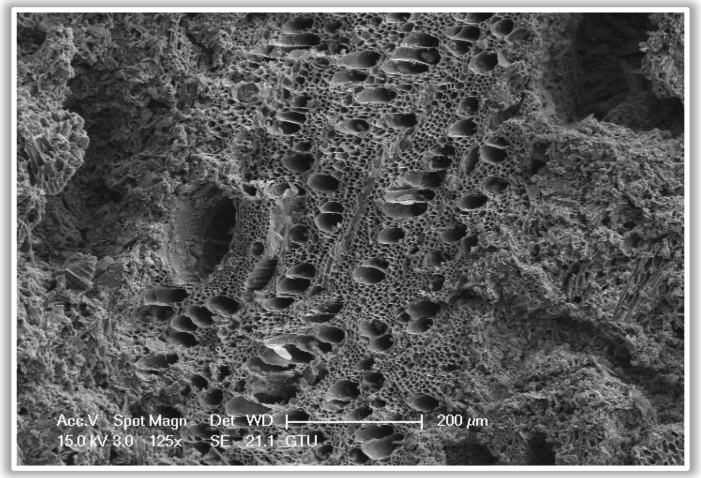
Methodology

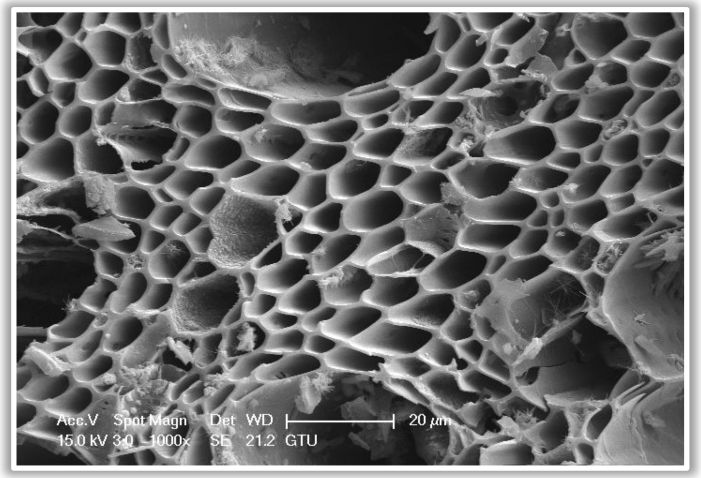
Biochar Based Diffuser Manufacturing

Manufacturing









There are few previous attempts to combine PS and biochar to mainly upgrade foam material (can be found w/ biochar foam keyword). This is the first study to manufacture a highly porous diffuser end-product.

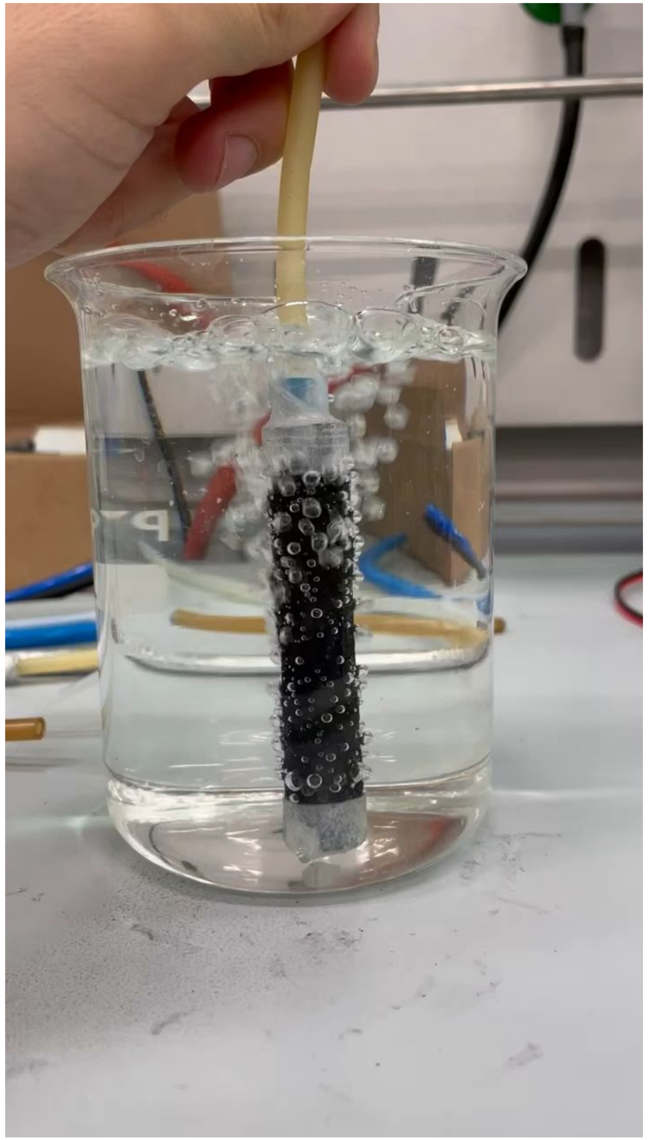
Methodology

First Complete Biochar Based Diffusers

- One of the initial complete biochar-based diffusers are presented to the right-side.
- At this moment we are able to manufacture even more **standardized** shapes at bigger scales with different geometry.
- A novel biomass originated **carbon-based affordable product** was achieved.

Parameters		Biochar-Diffuser
Material(s)	-	Biochar, Polysterene
Biochar : PS[1] Ratio	*M:M*	2.0
Active Length[2]	*mm*	65.0
Outer Diameter	*mm*	14.0 ± 1.5
Inner Diameter	*mm*	8.5 ± 0.5
Bulk Volume	*mL*	≈ 6.0

[1] Polystrene, [2] Length of the non-covered active part of the diffuser



Methodology

Analytical Methods and COD Approach

COD as a Single Unit to Track Chemical Energy Flow

- **Chemical oxygen demand (COD)** as a widely used unit mainly for water treatment purposes so far.
- Mainly monitored just for indirect measurement of the organic content of liquid samples' (e.g. wastewaters).
- Number of equivalent amount of oxygen required to oxidize all available organic compounds in a given volume of sample.
- In fact, **COD** is directly correlated to the energy content of any solid, liquid, and gas samples.

1kg COD = 0.125 kmol e^- ≅ 15 Mjoule

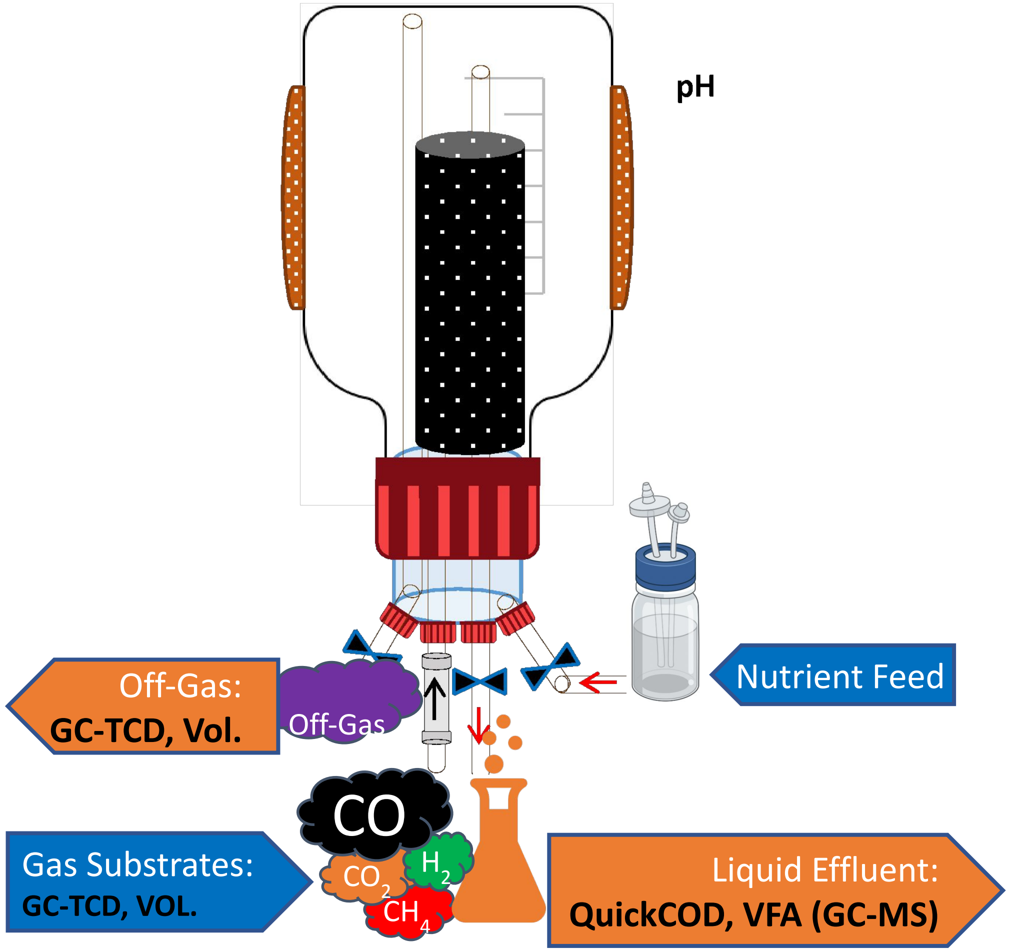
[e.g.: 1L-H_2 x 0.084 g-H_2/L x 7.94 g-COD/g-H_2 = 0.67g-COD/L-H_2]

- Allow to track chemical energy flow in biorefinery systems.

COD reactants = COD products

- Instead of mass balance, COD balance can be made for any biorefinery which usually deal with variety of input and output.

Analytical Equipments and Analysis Methods

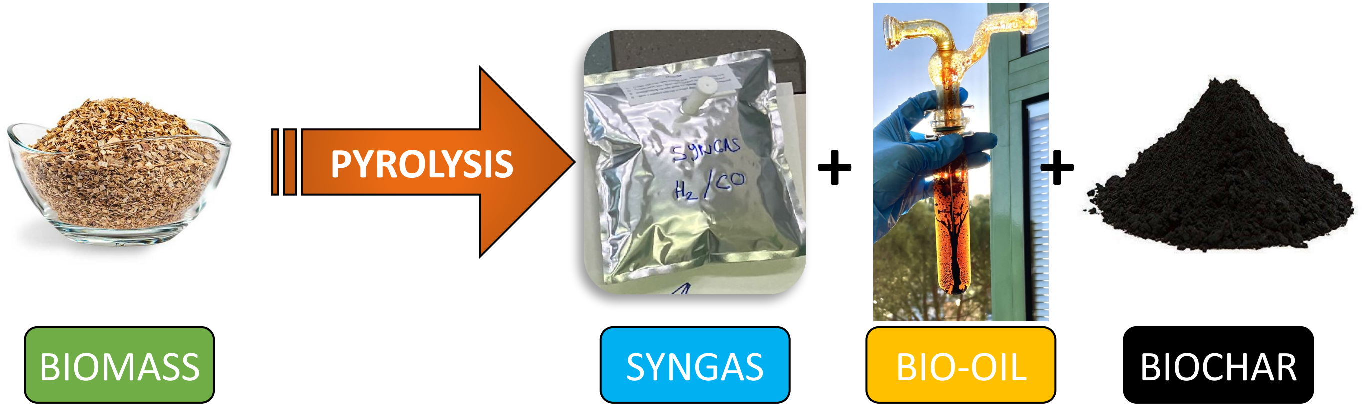


Reference: "Could pyrolysis substitute hydrolysis in 2nd generation biomass valorization strategies? A chemical oxygen demand (COD) approach", C. Torri et al., 2022 Journal of Analytical and Applied Pyrolysis.

(1) Thermochemical Conversion

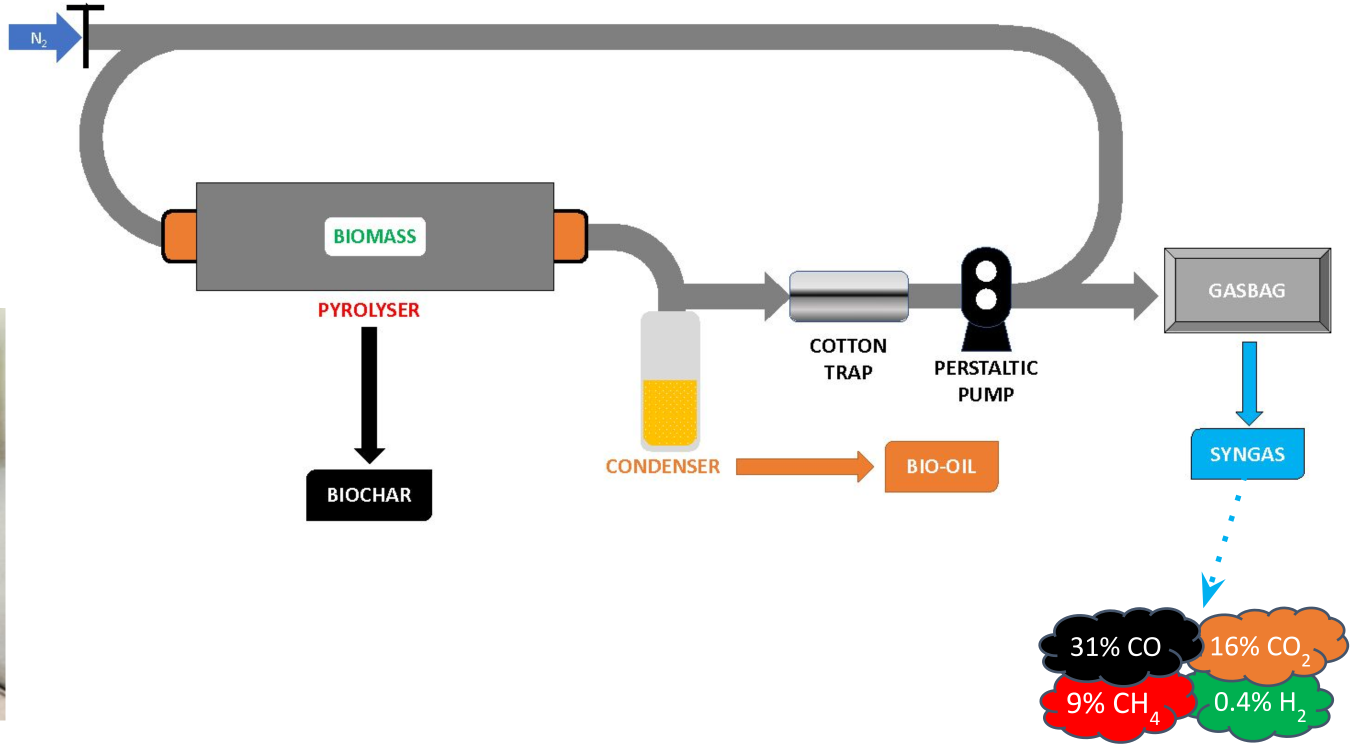
Intermediate Pyrolysis Derived Real Syngas

- Biomass is an abundant renewable source in the earth.
- Pyrolysis is an ancient and efficient thermochemical technique for biomass' chemical conversion.



Intermediate Pyrolysis Conditions

- **Fir Sawdust** used as representative lignocellulosic biomass.
- Batch pyrolysis conducted at moderate heating rate (**550°C for 30 minutes**) under gas recirculation.

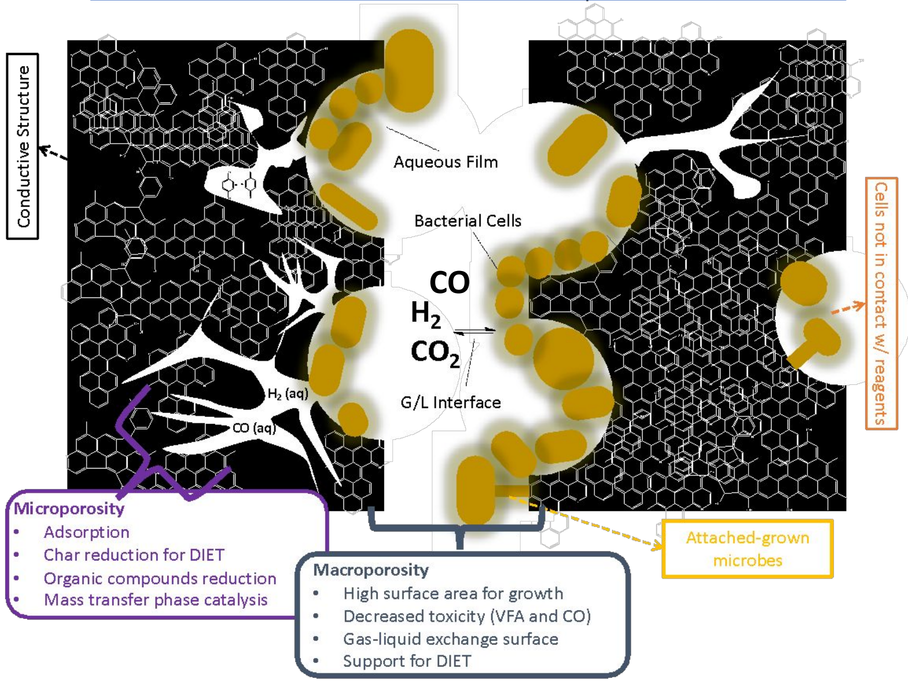


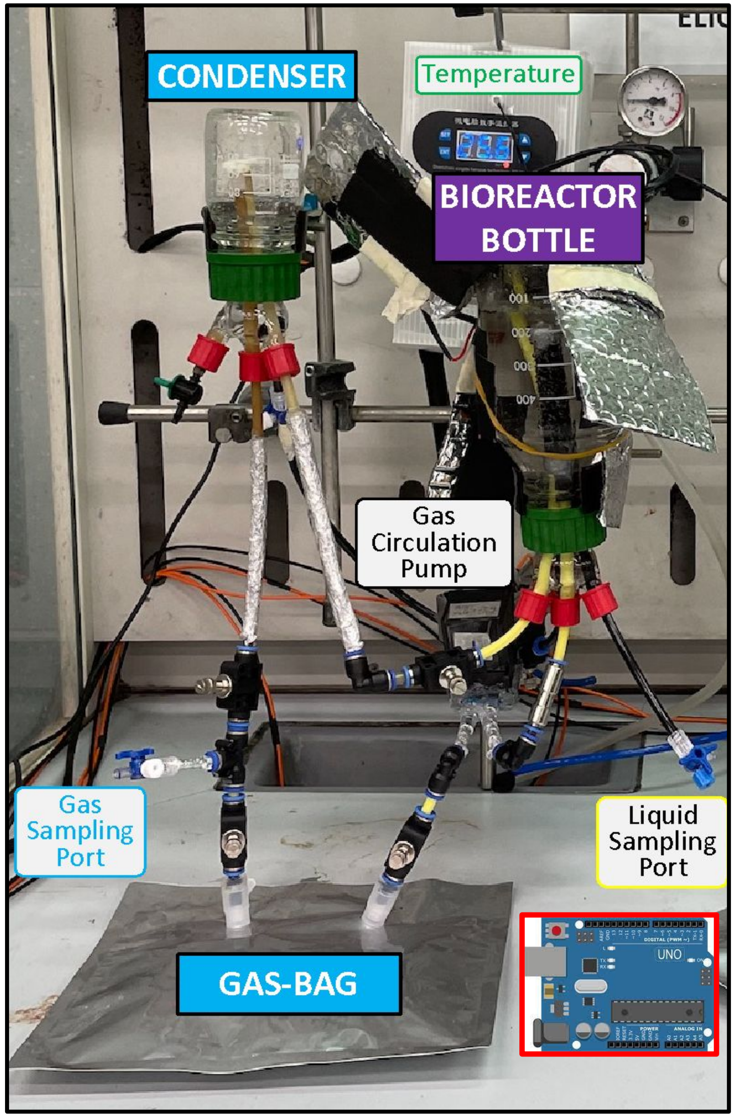
(2) Syngas Fermentation

Integration of MMC and Biochar Composite Material

- Bioreactor set-up was designed and constructed by the research team.
- Arduino is the key tool for configurable (flexible) bioreactor set-up with cost-efficiency.
- Four-ported (tetrapod) bottle caps provides sufficient inlet and outlet for such complex bioreactors.
- Pneumatic adapters and pipes together with gas-tight valves and pumps are required for such system.
- A small condenser bottle was combined to minimize water vapor losses.

Parameters		R-1 Syngas Reactor
Substrate Material	-	Syngas
Operational Method	-	Daily Fed Continuous
Temperature Set	°C	36.0
Total Wet Volume	mL	500.0
Hydraulic Retention Time	days	25
Avarage Gas Loading Rate	g-COD/L-day	0.53 ± 0.14
Sodium Bicarbonate Level	g/L	40.0
Start-Mix Concentration	g-COD/L	10.0
Inoculum : Glucose : Medium	COD basis	40% : 50% : 10%
Initial BES Concentration	mM	10.0

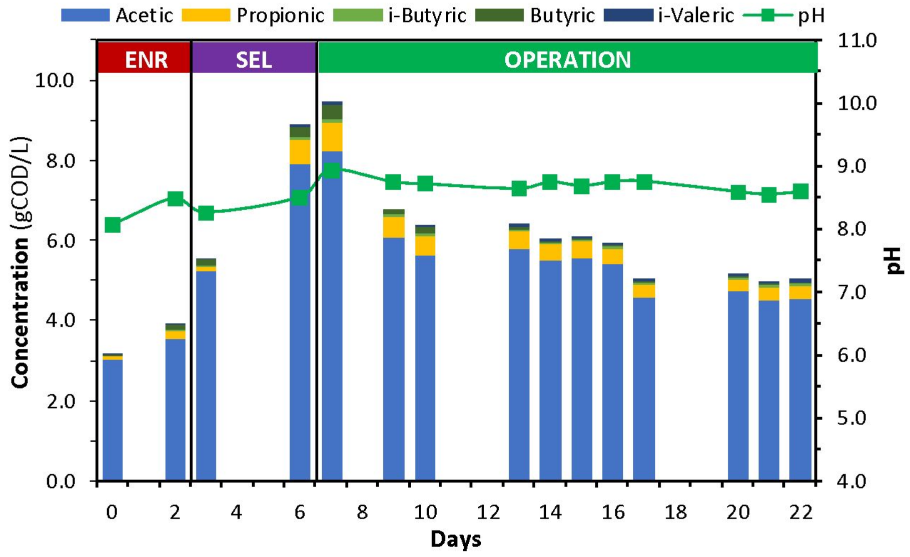




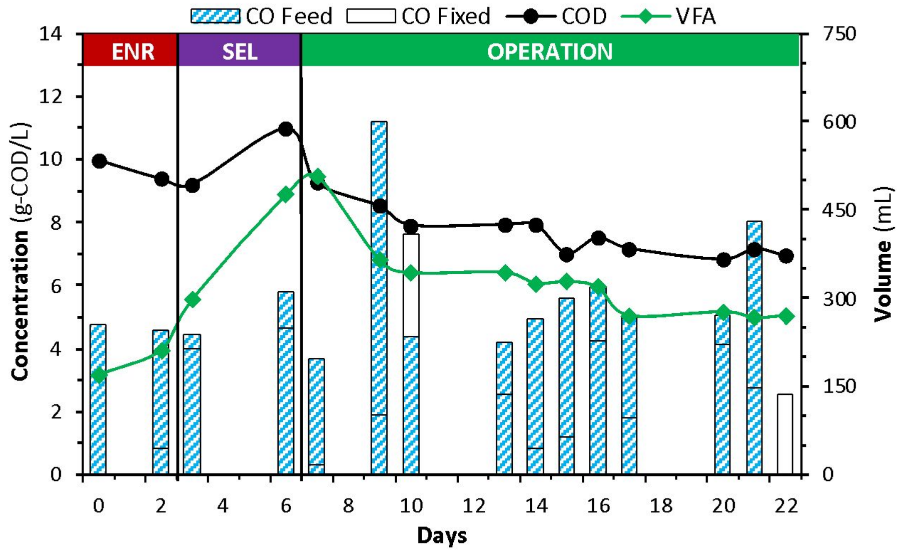
(2) Syngas Fermentation

Integration of MMC and Biochar Composite Material

- Over 75% of effluent COD was contributed by VFA production.
- Low effluent suspended COD content (< 250ppm) with pH 8.5 is favorable for the subsequent PHA bio-accumulation process.
- Initial glucose originated COD is extracted from the performance estimations.
- These promising preliminary results suggesting that, this biochar based real syngas fermentation approach can be exploited for the production of VFA-rich liquids.
- To achieve better productivities, larger biochar diffuser is required, which should occupy most of the wet volume.



Parameters	Unit	Syngas Reactor (R-1)
Total Input	*g-COD*	11
Total Output	*g-COD*	10
Overall COD Recovery	*%*	> 90%
Effluent VFA to COD Ratio	*%*	77% ± 6
$Diffuser_{BASED}$ VFA_{NET} Productivity	*g-COD/L-day*	5.0
$Volumetric_{WET}$ VFA_{NET} Productivity	*g-COD/L-day*	0.06



(3) PHB Bio-Accumulation

Fully Continous Lab-Scale System:
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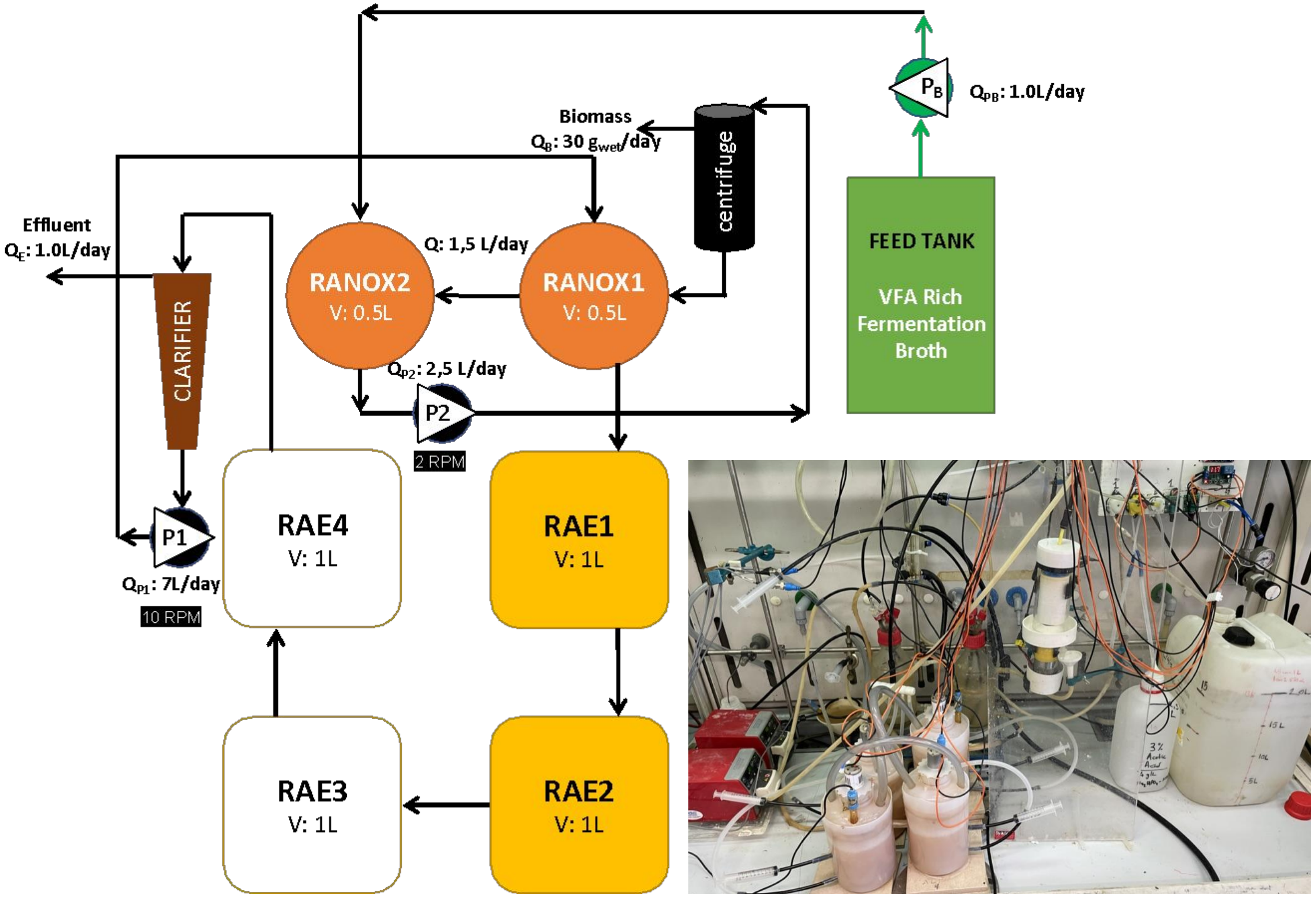

- Instead of much more common fully aerobic feast/famine operation, where especially C/P ratio has to be regulated, a sequantial microaerophilic - aerobic PHA accumulation system is proposed [REF].
- To avoid any chemical adjustment (presence of nutrients; N / P) for the fermentation effluent prior to the PHA accumulation system.
- Feast and famine regimes are sustained via sequantial several reactors.
- A continous small-scale centrifuge was developed to ensure continous biomass wihdrawn.
- 34% of PHB content has achieved by the MMC s far.

Reference: "Activated sludge as a possible source of biodegradable plastic" Satoh H. et al. 1998 Water Sci & Tech

Conclusion

- Integrated but simplified biorefinery approach for PHA from biomass.
- Direct bio-utilisation of pyrolysis derived real syngas with biochar presence is possible.
- Acetic acid and nutrient rich fermentation broth with pH≈8 is ideal for PHA-producers.
- No chemical adjustment or pre-treatment is required, thanks to sequantial MMC systems.
- Chemical methanogen inhibitor (BES) increasing the cost.
- Gasifier derived syngas bio-utilisation still required to be confirmed.
- Syngas fermentation productivity should be increased (larger and better bio-diffsuers).

Thank you for your attention!

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