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VSB TECHNICAL UNIVERSITY OF OSTRAVA

ENERGY AND ENVIRONMENT

SEPTEMBER 7-9, 2026

# Advances in Low-Temperature Biochar Production for Circularity and Sustainability


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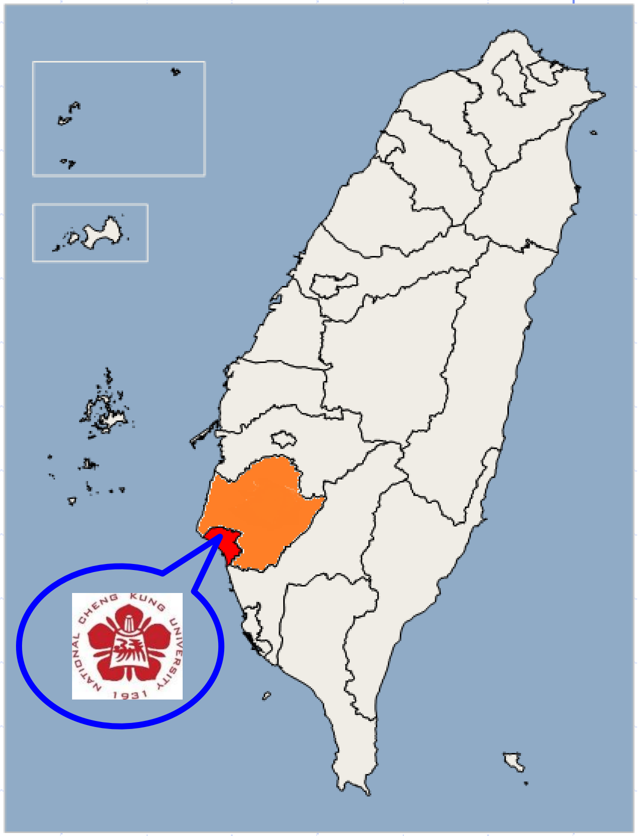
**September 8, 2026**

Green Energy and Fuel Laboratory
GENFUEL

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

# National Cheng Kung University

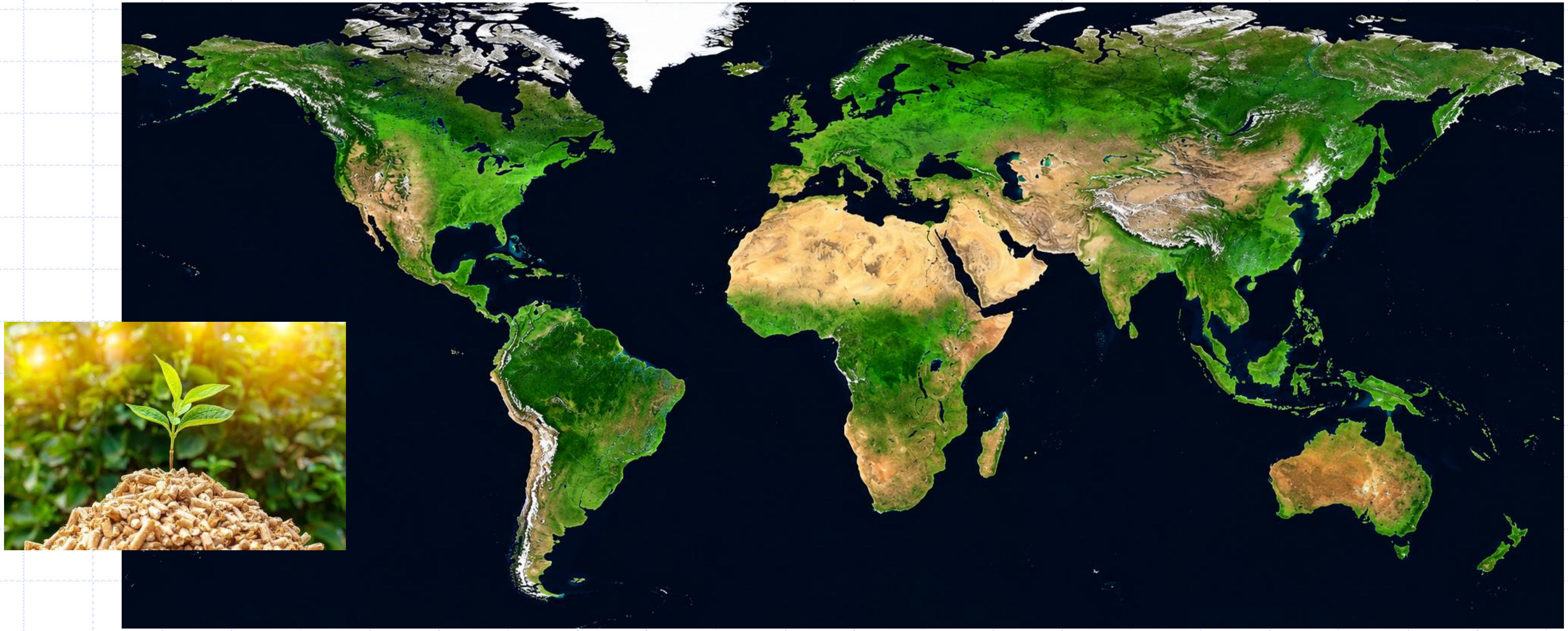

# Outline

- Biomass & Bioenergy
- Biochar
- Torrefaction & Spent Coffee Grounds

# Biomass & Bioenergy

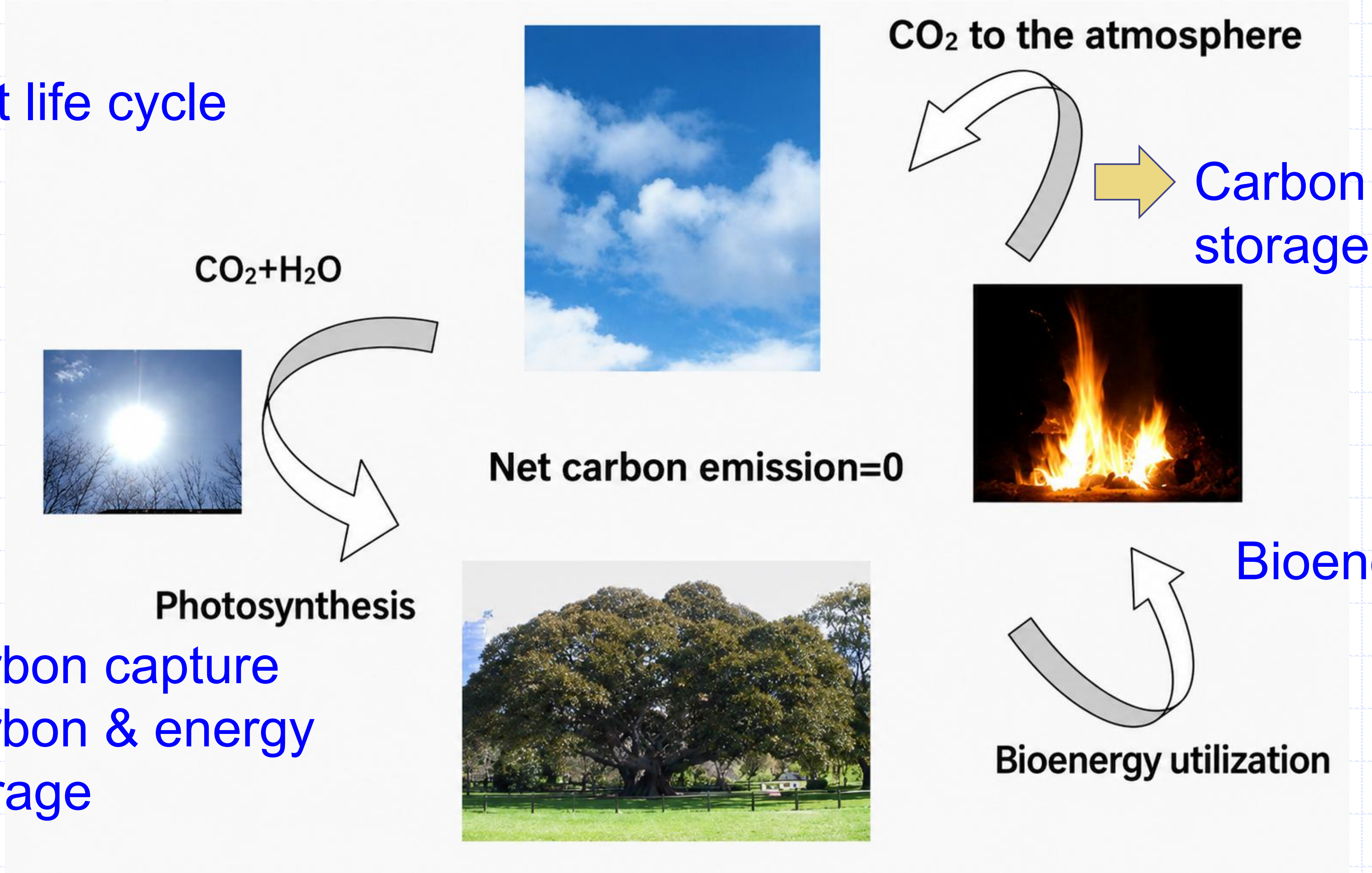
# Global Vegetation

Biomass is a global & abundant resource (food, energy and fuel, and carbon storage)



# Circular Biomass

Short life cycle




Carbon capture & storage

Bioenergy

Carbon capture
Carbon & energy storage

National Cheng Kung University

# Biomass

## Conversion / Biorefinery

### Solid
- Biochar, firewood, charcoal, AC …
- Powder, pellet, block, briquette …

### Liquid
- Biodiesel
- Bioethanol
- Bio-oil
- Biobutanol …

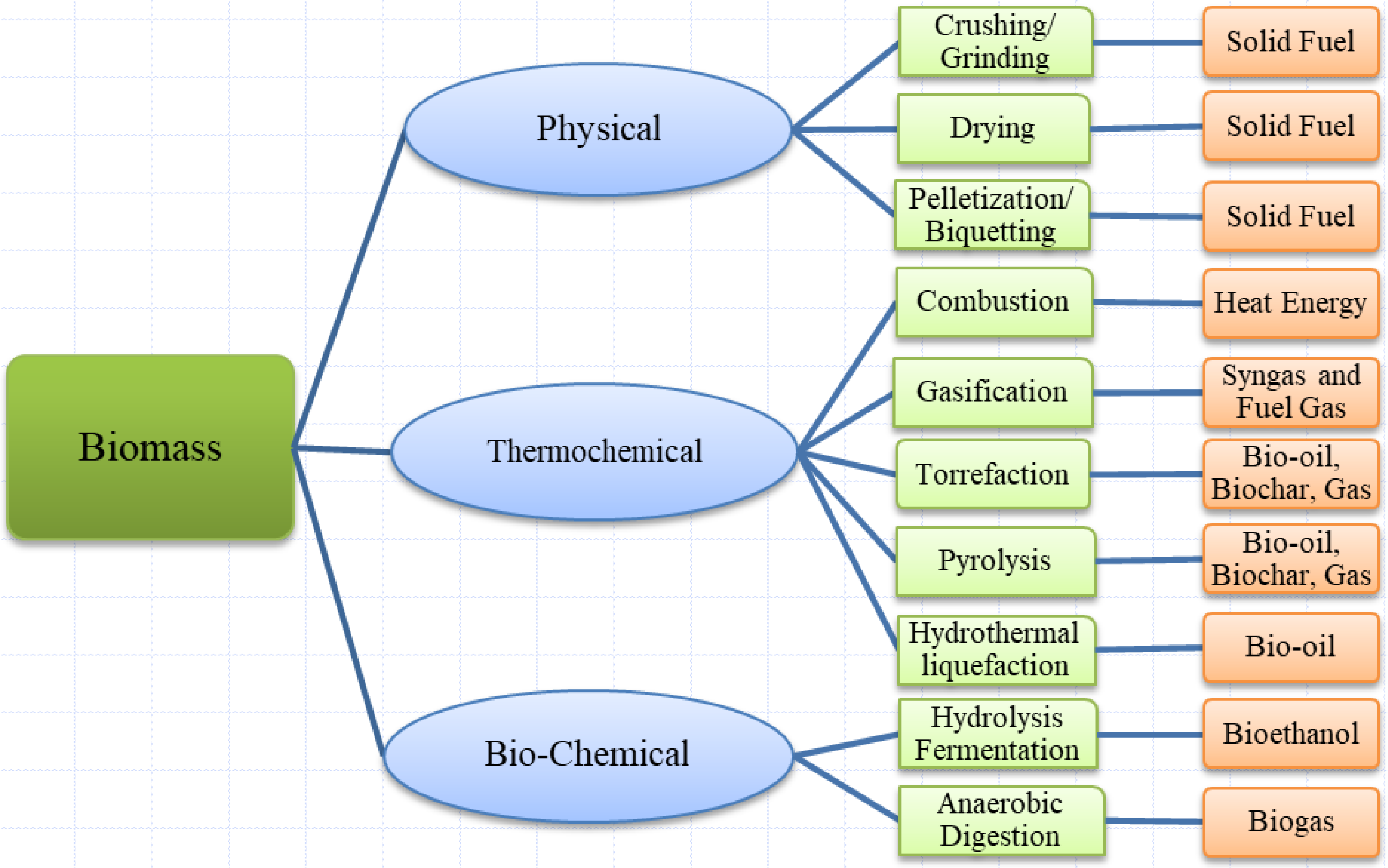
### Gas
- Syngas
- Biogas
- Biohydrogen …

Fuel
(Carbon Neutral)

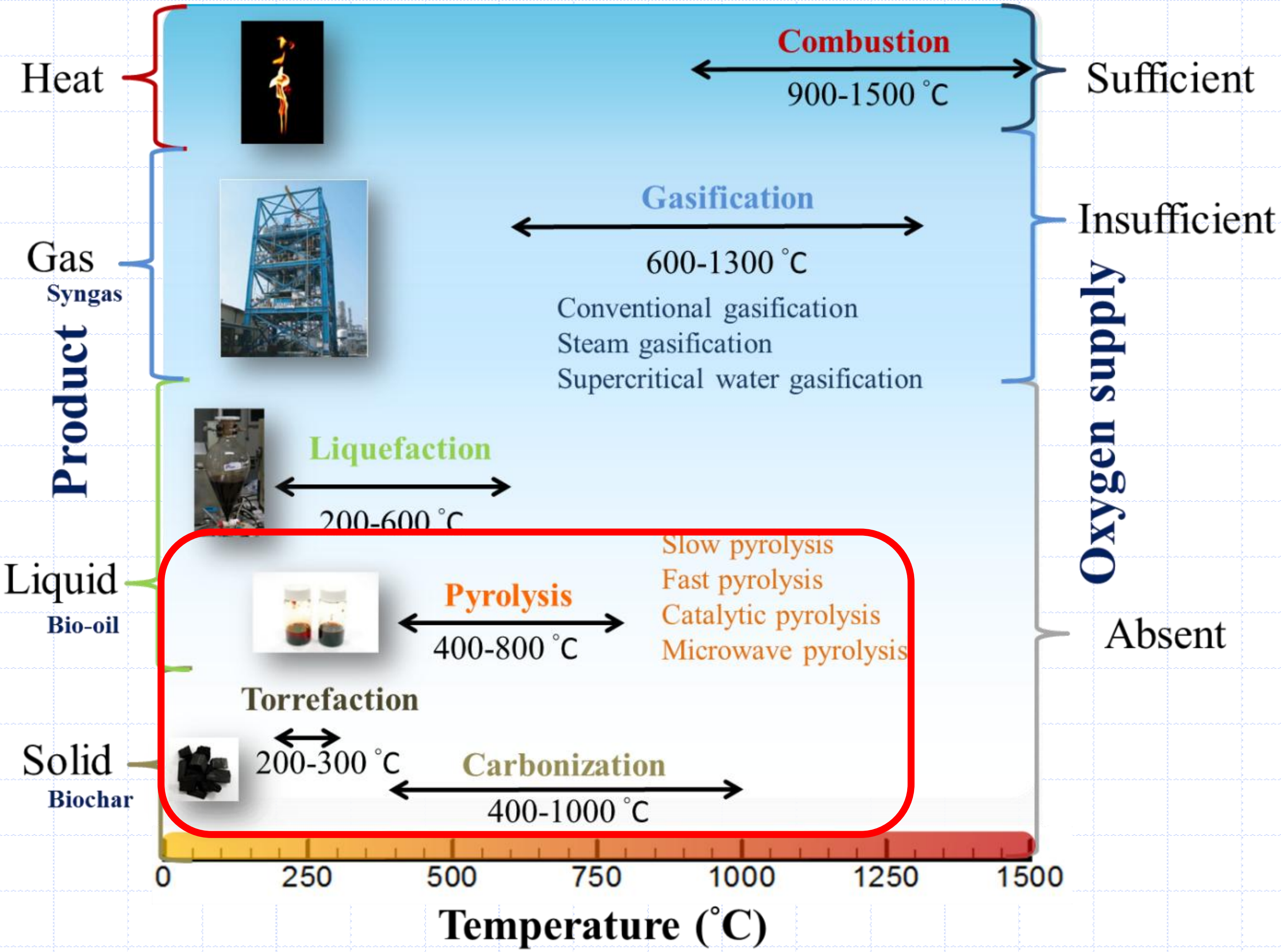
Materials & Chemicals
(Carbon Negative)

Waste Valorization
(Circular Bioeconomy)

# Biomass Conversion

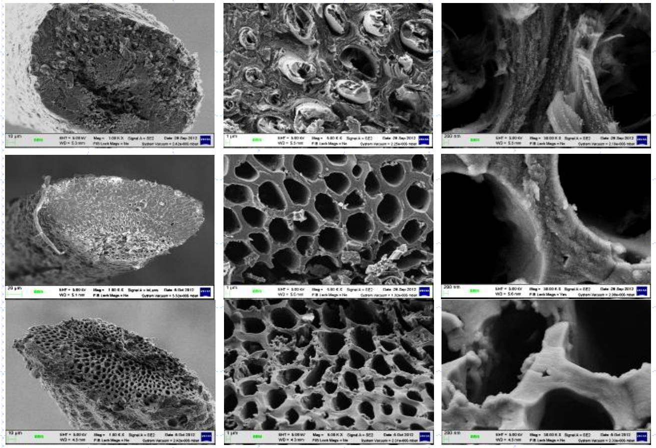


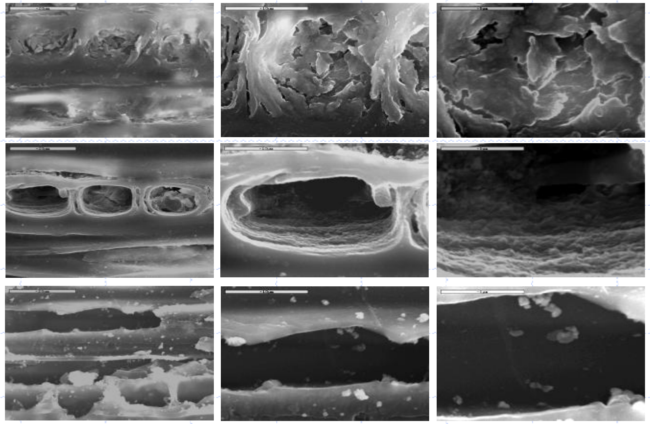
# Thermochemical Conversion



# Biochar

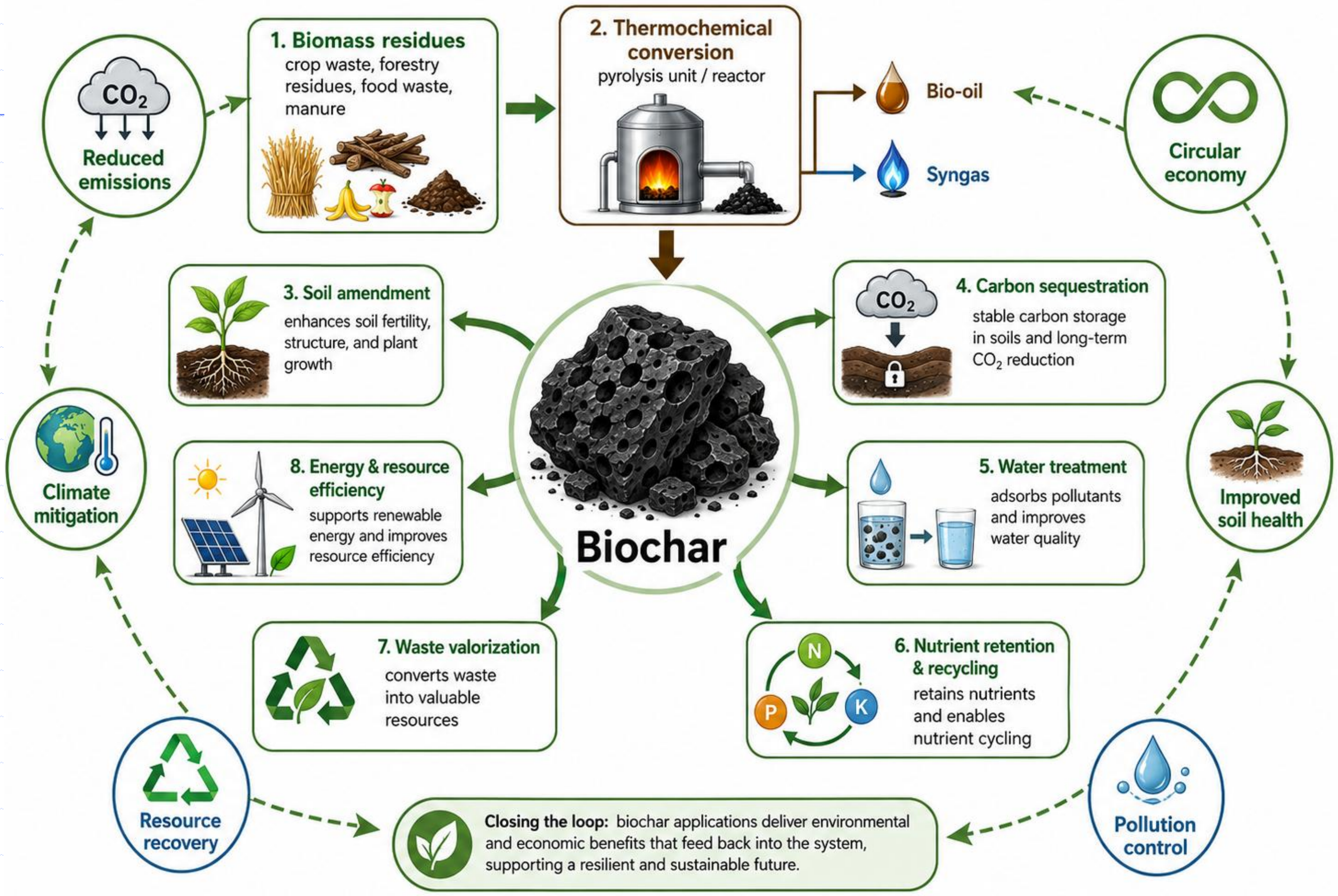
# Biochar



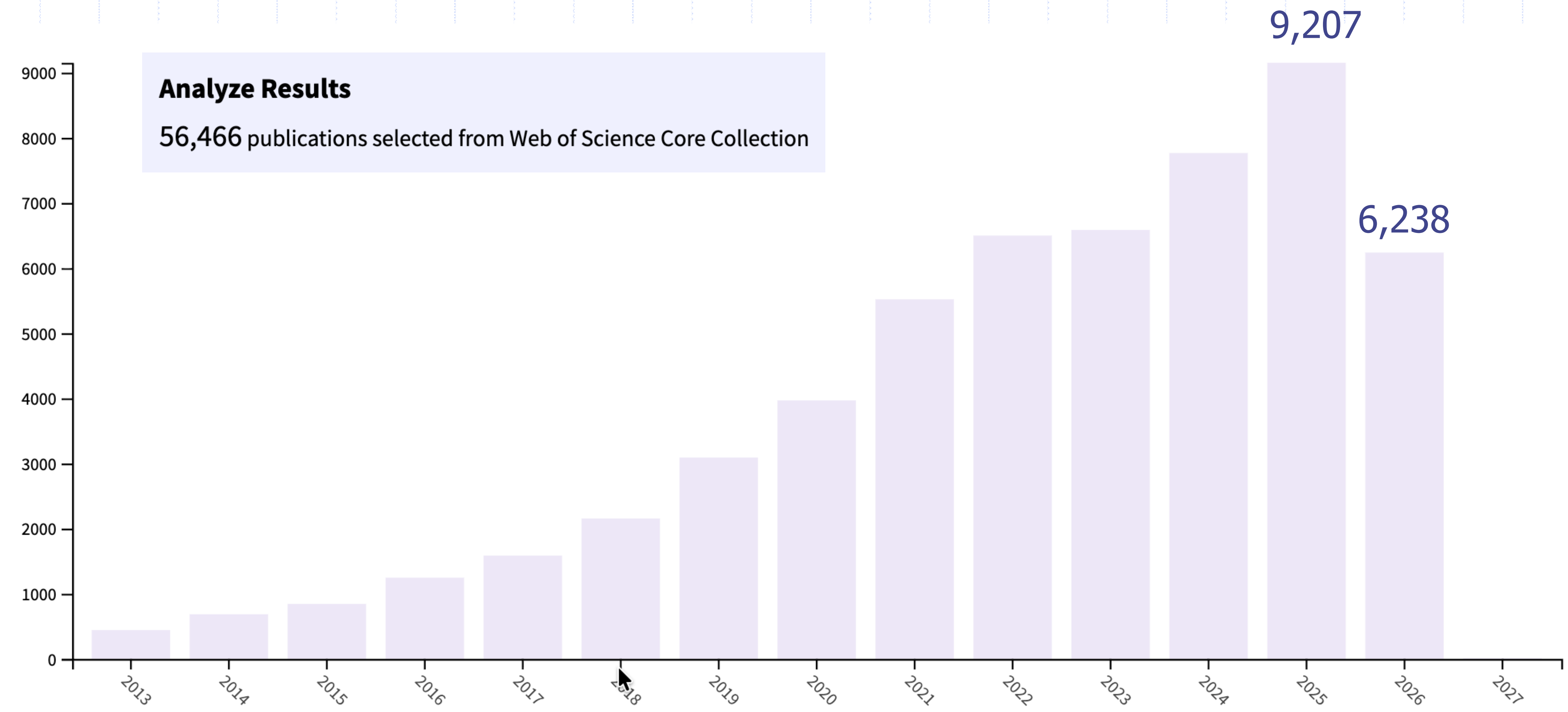


A carbon-rich and porous solid produced from biomass thermodegradation under a limited or no oxygen environment.

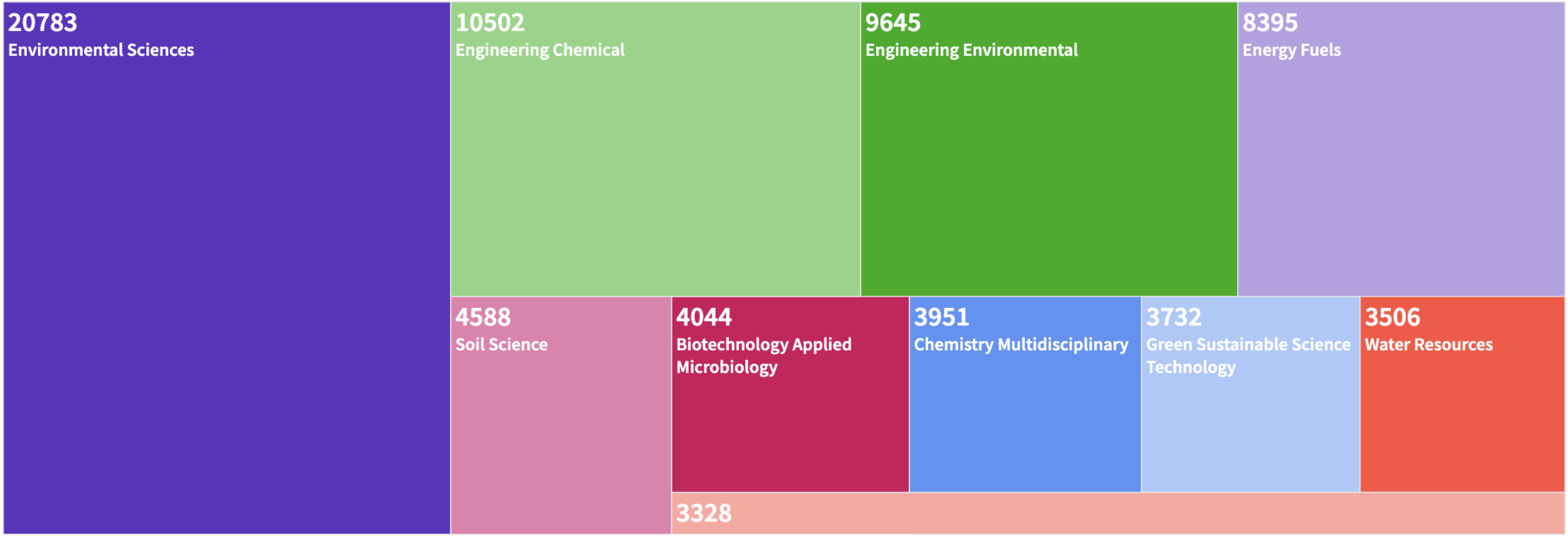
# The role of biochar in circularity and sustainability



# Biochar Research



# Biochar Research



# Torrefaction

# Disadvantages



Hygroscopic behavior

High Moisture

Large Volume

Higher Biodegradability

Low Grindability

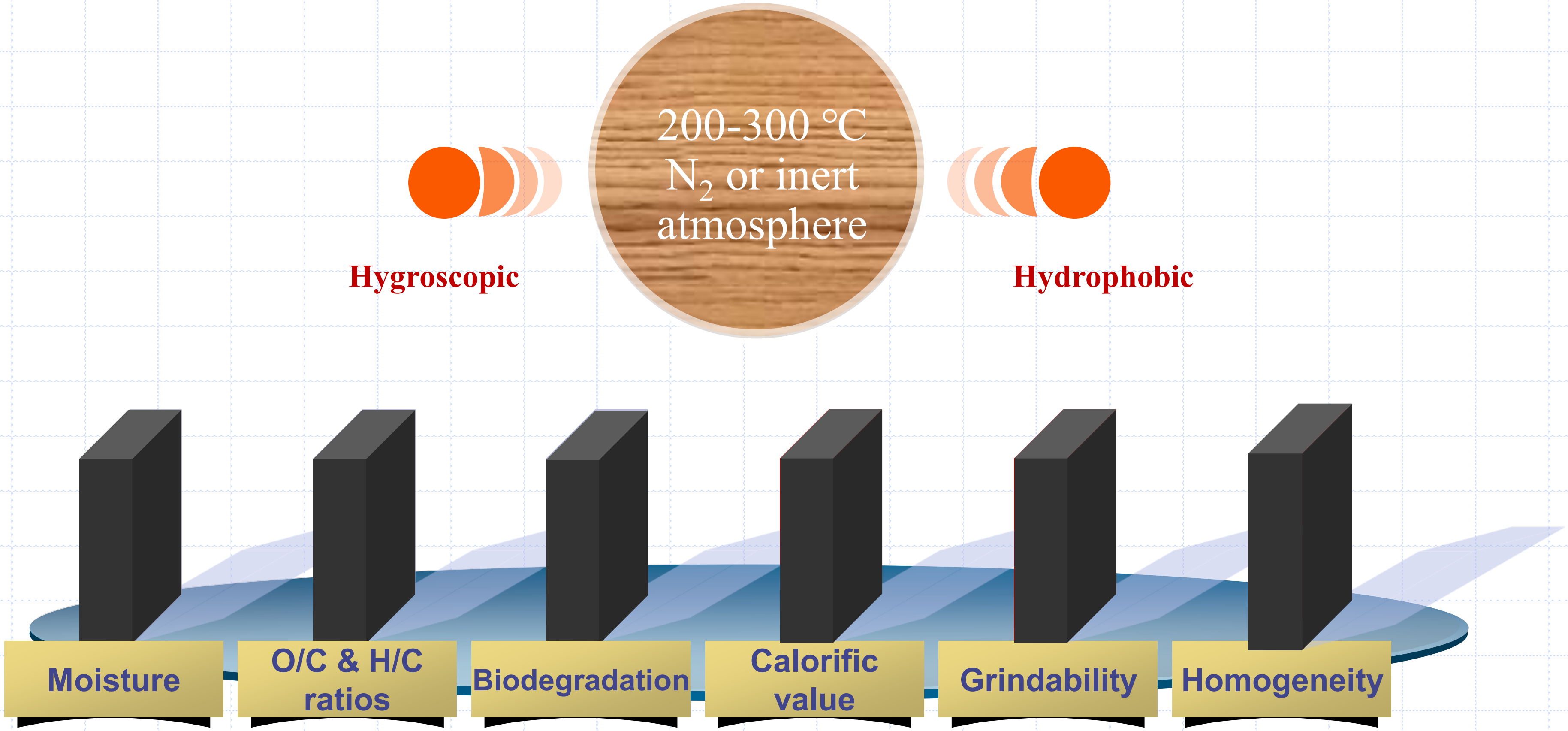
Low Energy Density

Biomass


Difficulty in storage
High cost in transport
Low utilization efficiency

# Torrefaction

- Torrefaction is a mild pyrolysis process for biomass pretreatment



# Linear vs. Circular Economy

Waste
- Disposal
- Treatment
- Recovery & Recycle
- Valorization


Linear economy


Circular economy

https://atriainnovation.com/en/blog/circular-economy/

# Coffee

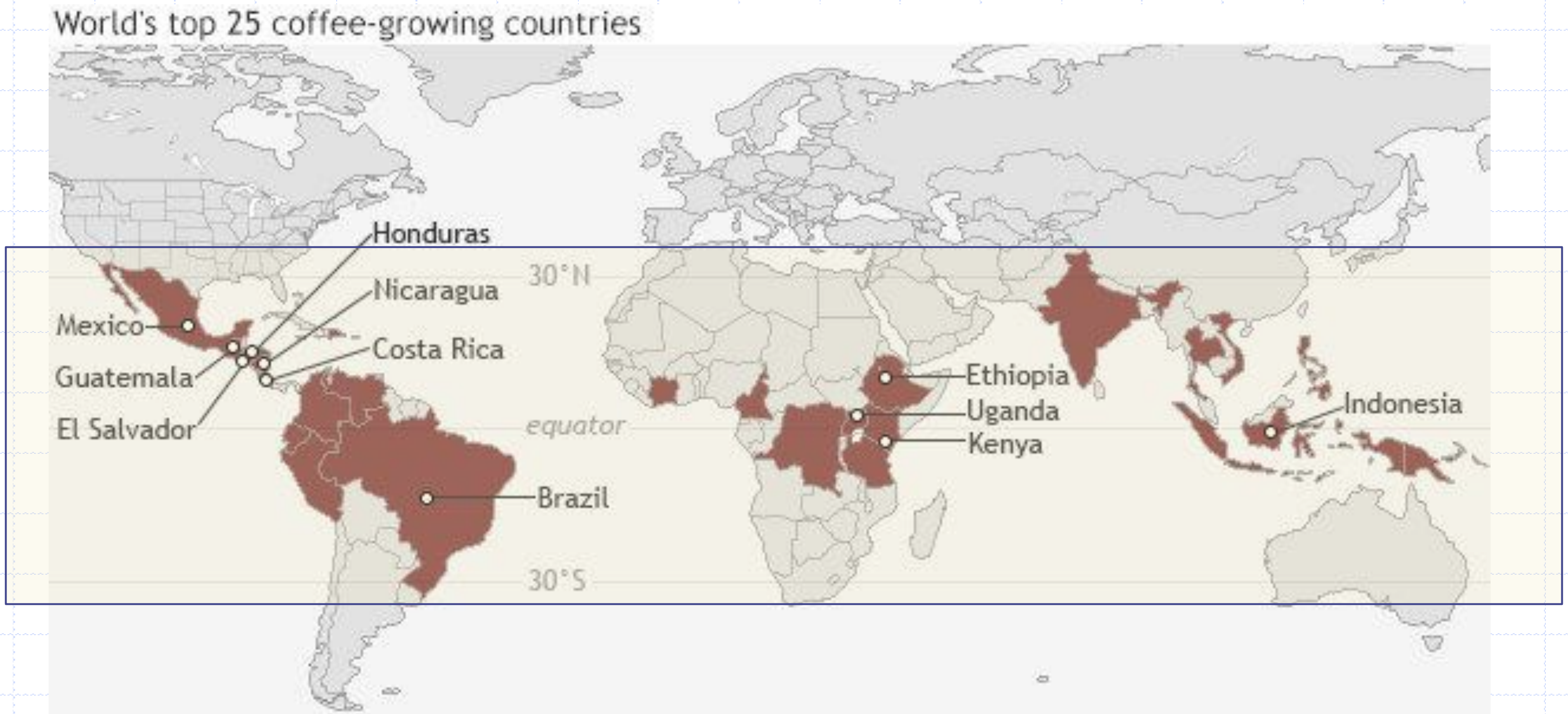

PLATE XI.—*Coffea arabica* (Coffee). (From Jackson: *Experimental Pharmacology and Materia Medica.*)

Arabica

Robusta

- Coffee is a plant of the Rubiaceae family, which is beneficial to the stomach, brain, and blood, etc.
- There are about forty types of coffee beans, but there are only three types of coffee beans with marketing value, namely Arabica, Robusta, and Liberica.

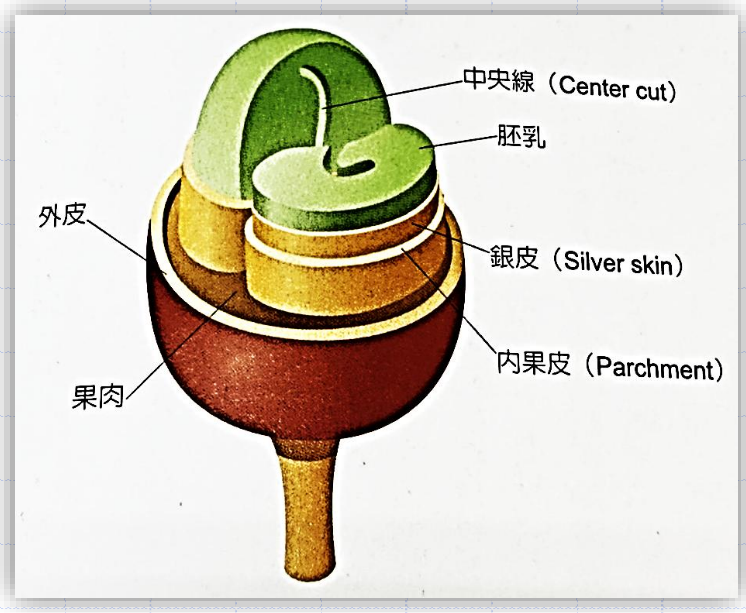
# Coffee Belt




Optimal coffee-growing conditions include cool to warm tropical climates, rich soils, and few pests or diseases. The world's Coffee Belt spans the globe along the equator, with cultivation in North, Central, and South America; the Caribbean; Africa; the Middle East; and Asia. Brazil is now the world's largest coffee-producing country.

https://www.climate.gov/news-features/climate-and/climate-coffee

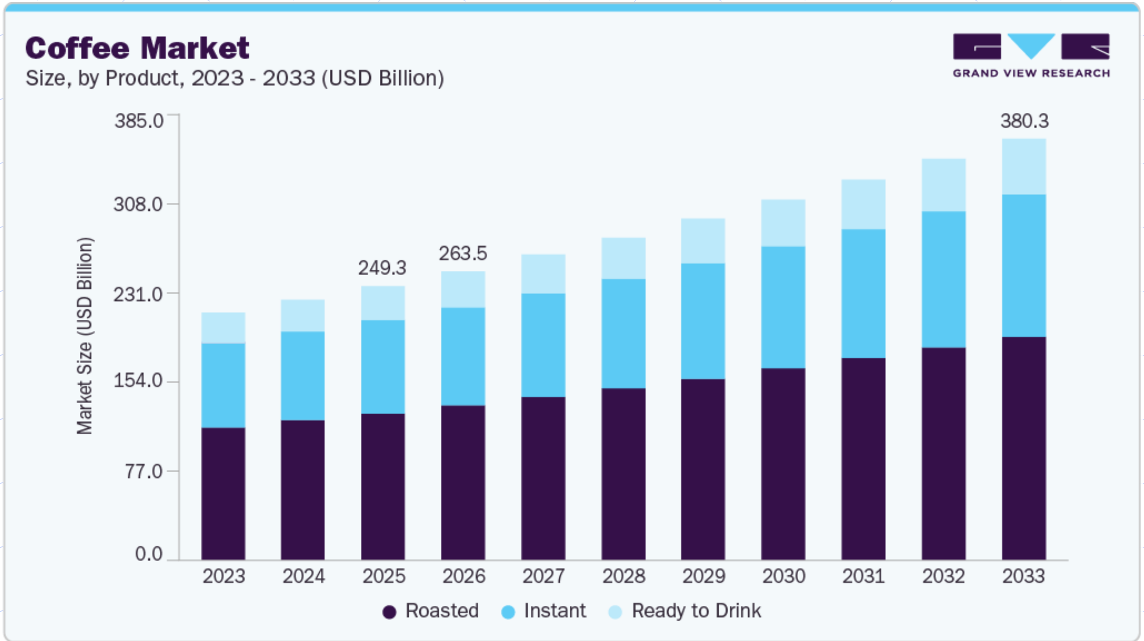
# Coffee Bean





- Coffee beans are composed of center cut (中央線), endosperm (胚乳), silver skin (銀皮), parchment (內果皮), pulp (內果肉), and outer skin (外皮).
- The time from sowing to the harvest of coffee beans is about 3 years.

# Coffee Consumption


- ➢ Global coffee consumption has been steadily increasing over recent years. In the 2024/25 coffee year, global coffee consumption was 175.1 million 60-kg bags, equivalent to about 10.5 million metric tons.
- ➢ The International Coffee Organization (ICO) reported that in the 2024/25 coffee year, global coffee production reached 177.5 million bags (around 10.7 million tons).

https://www.grandviewresearch.com/industry-analysis/coffee-market

# Spent Coffee Grounds

- A cup of coffee uses about 10 grams of coffee grounds on average, and the leftover coffee residue is approximately 9 grams.
- Approximately 6.8 million tons of coffee grounds are generated worldwide each year (2024/2025).

# Environmental Problems

- Decomposing SCGs release methane, contributing to climate change.
- When disposed of in landfills or in the soil, the high acidity of SCGs can disrupt soil pH balance, harming plant growth.

- SCGs may leach compounds (e.g., caffeine, tannins) into the soil or water, contaminating ecosystems.

- Large volumes of SCGs contribute to landfill overloading and reduce the space available for other wastes.

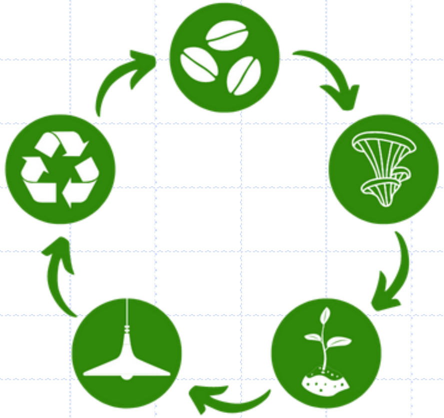
# bio-bean powered by coffee @UK



- ➢ A biofuel created by blending oil extracted from coffee waste with diesel is to be added to the public transport fuel supply.
- ➢ Bio-bean says it has produced enough coffee oil to power one bus for a year.

PERMAFUNGI
Eat·Grow·Learn

# @Belgium

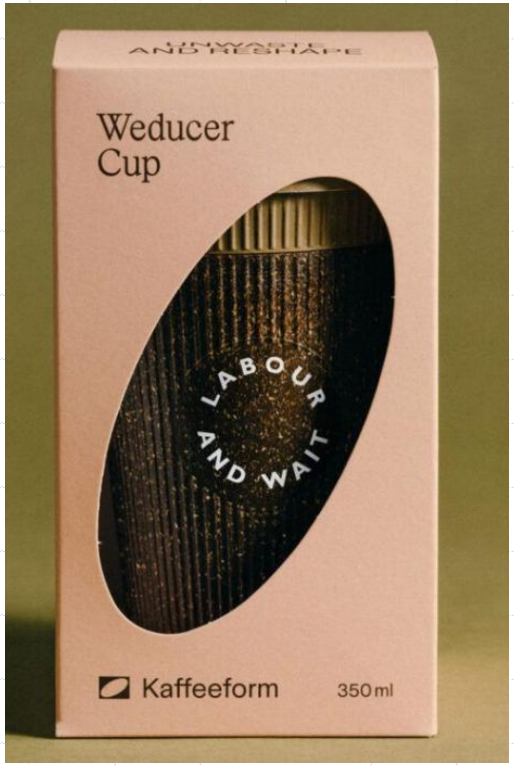


With the coffee grounds gathered by bike, one ton of fresh oyster mushrooms and ten tons of organic fertilizer are produced by recycling 5 tons of coffee grounds.

All of it in a circular economy!

# KAFFEE FORM. @Berlin, Germany

- Daily use products such as coffee cups

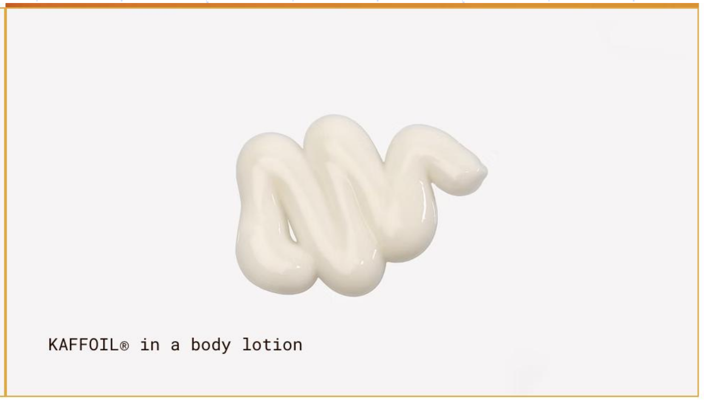




# KAFFE BUENO @Denmark

- Coffee biorefinery for personal care


KAFFOIL® in a hair oil


KAFFOIL® in a body lotion

## #rens @Finland


## Xpresole @Taiwan


# Spent Coffee Grounds & Circular Economy

**Publications**
277
Total
From 2000 to 2026

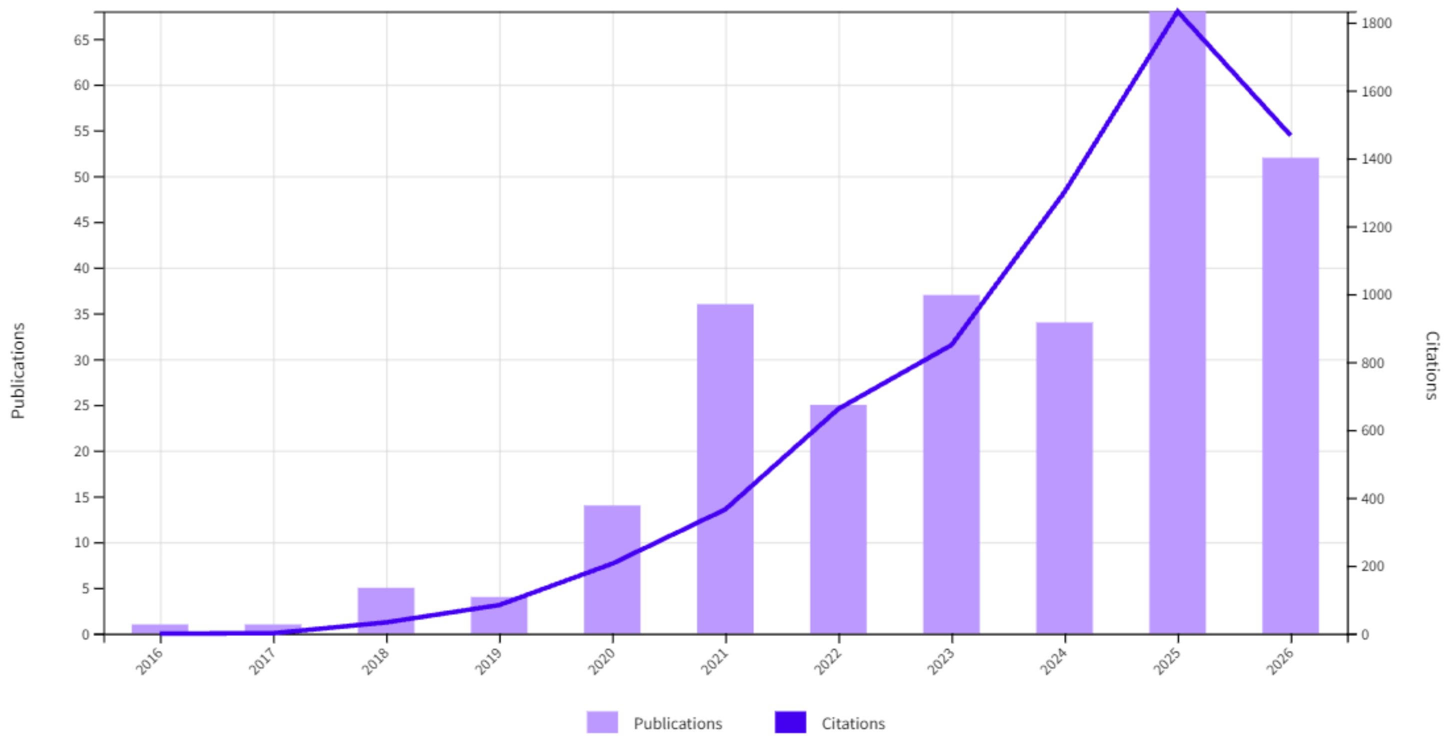
**Citing Articles**
5,319 Analyze
Total
5,142 Analyze
Without self-citations

**Times Cited**
6,805
Total
24.57
Average per item
6,299
Without self-citations

46
H-Index

**Times Cited and Publications Over Time**

DOWNLOAD

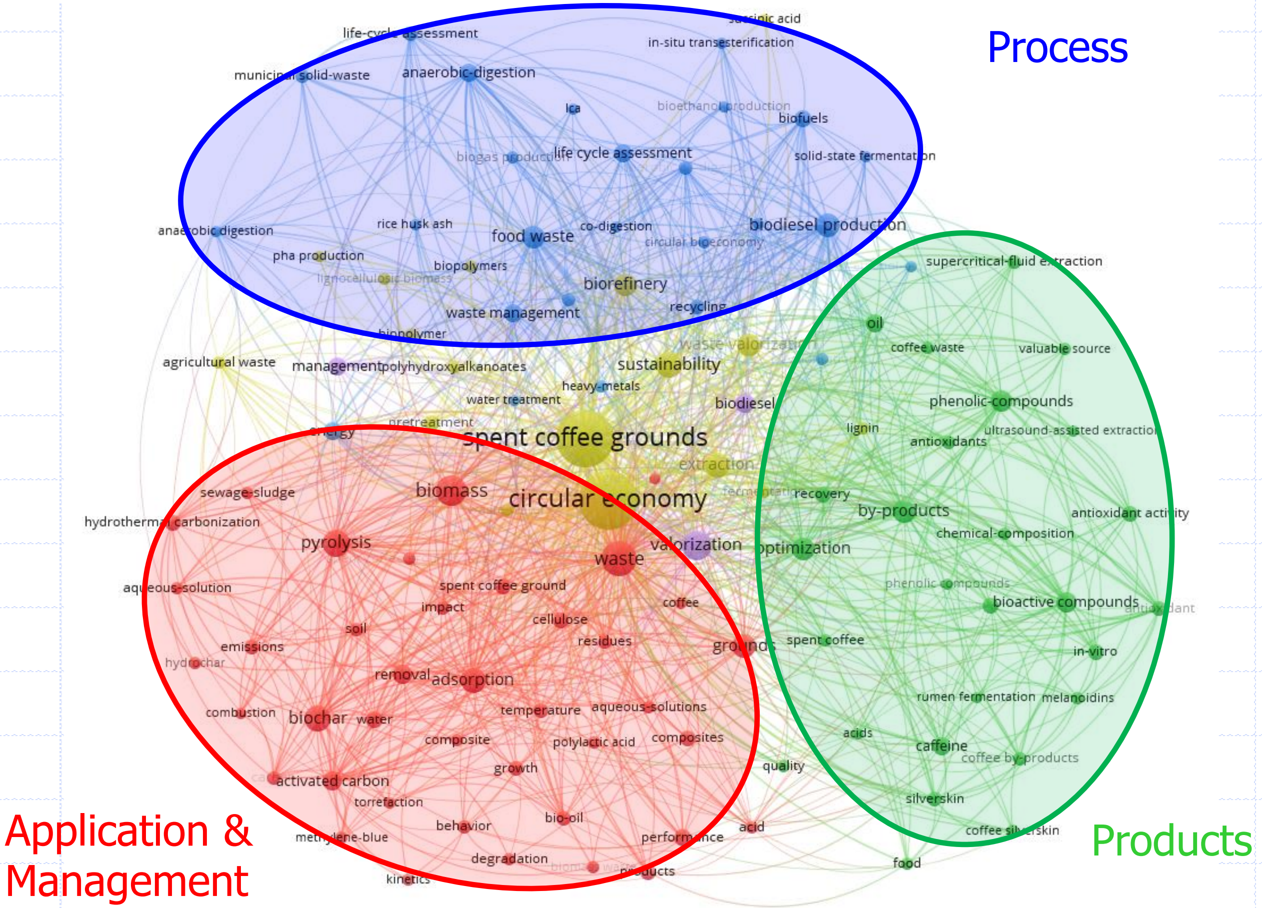


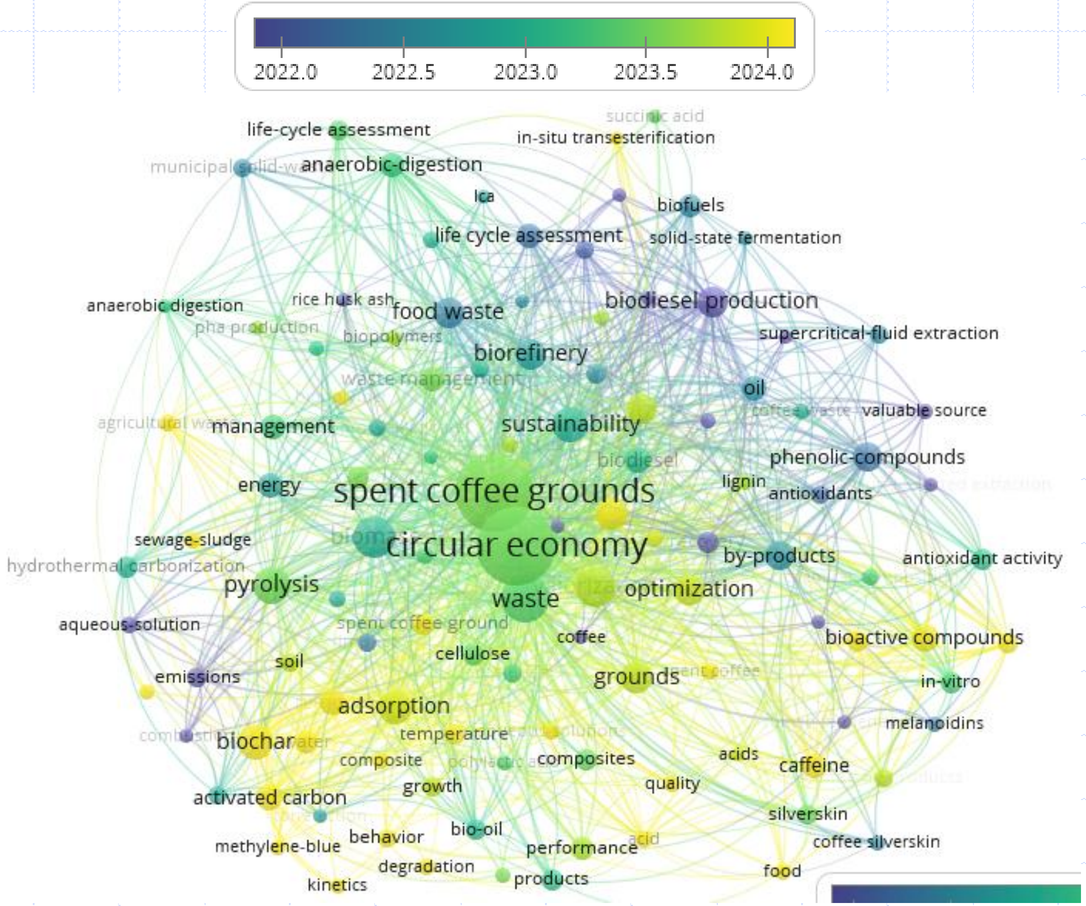
# Spent Coffee Grounds & Circular Economy

National Cheng Kung University

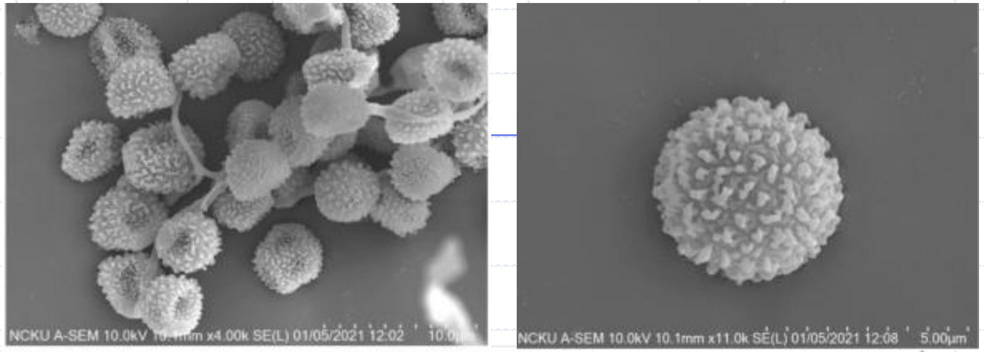
## Keywords: spent coffee grounds & Circular Economy

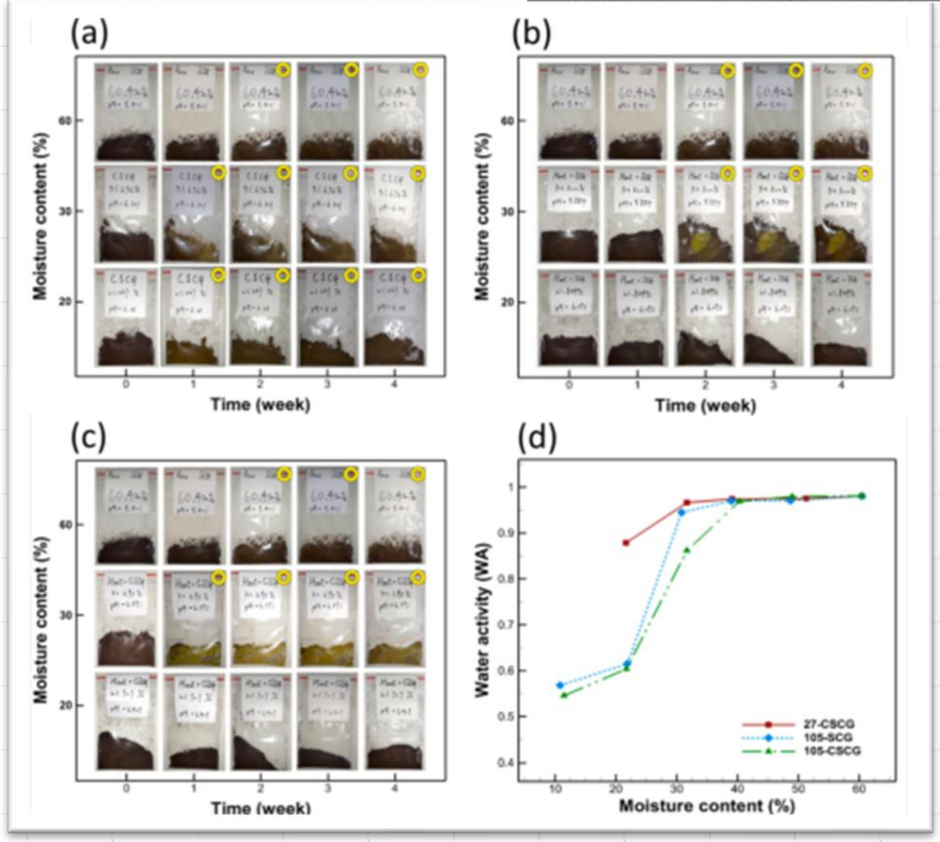
VOSviewer

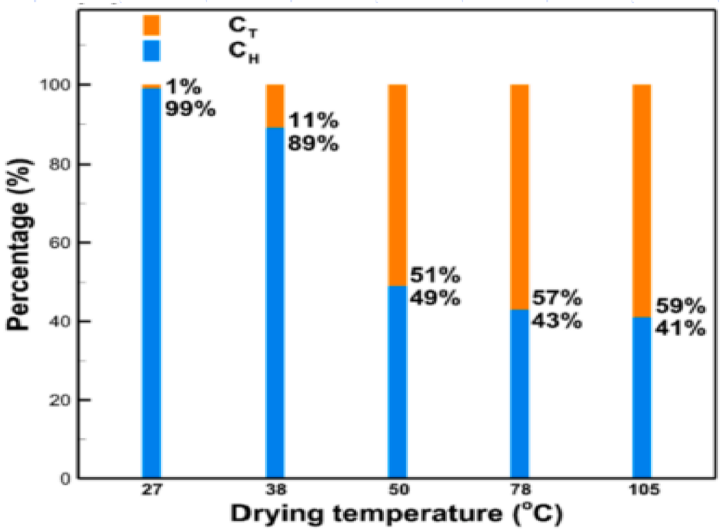


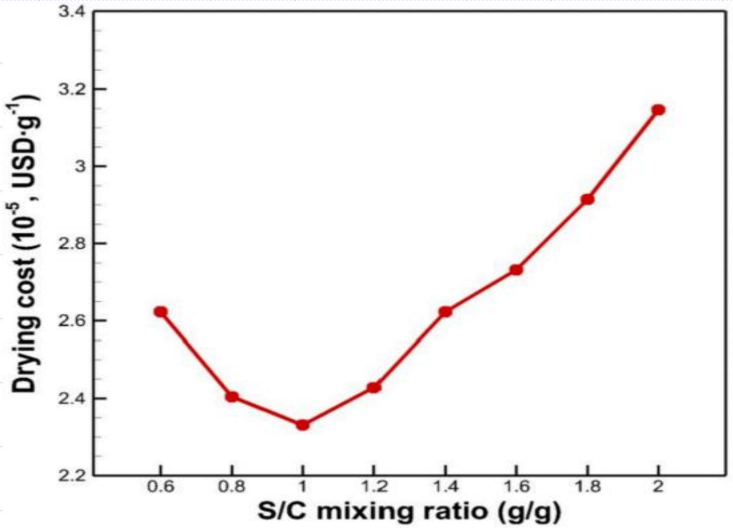



Mold



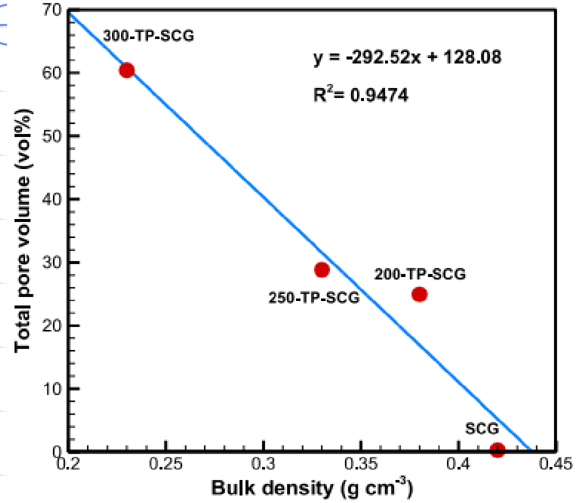



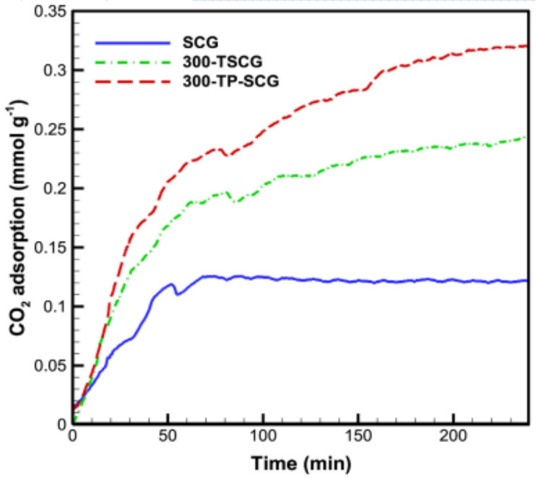



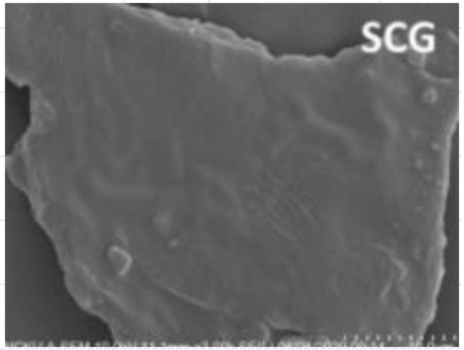



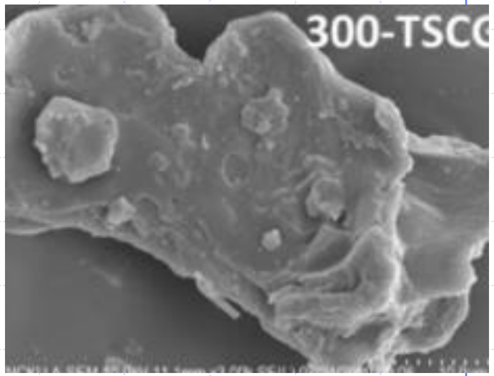

| Biomass | SCG |
|---|---|
| Photograph |  |
| Proximate analysis (wt%, dry basis) | |
| Volatile matter (VM) | 79.16 |
| Fixed carbon (FC) | 19.38 |
| Ash | 1.46 |
| Elemental analysis (wt%, dry-ash-free) | |
| C | 52.98 |
| H | 7.59 |
| N | 3.78 |
| S | 0.31 |
| O (by difference) | 35.34 |
| H/C | 1.72 |
| O/C | 0.5 |
| Moisture content (wt%) | 60.42 |
| pH | 5.411 |
| HHV (MJ·kg$^{-1}$, wet basis) | 9.613 |
| HHV (MJ·kg$^{-1}$, dry basis) | 23.468 |

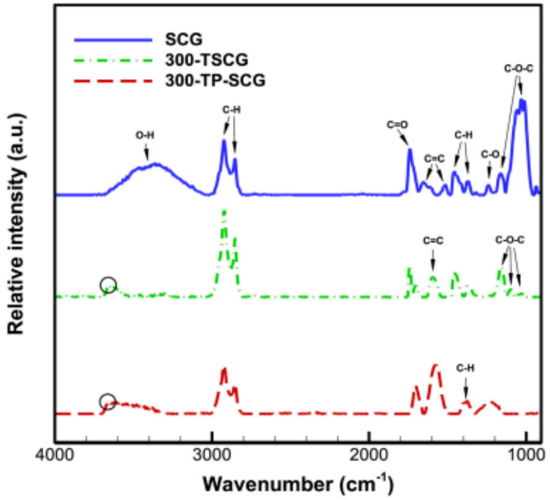
- Heterogeneous mixing strategy can save the drying cost up to 44%.

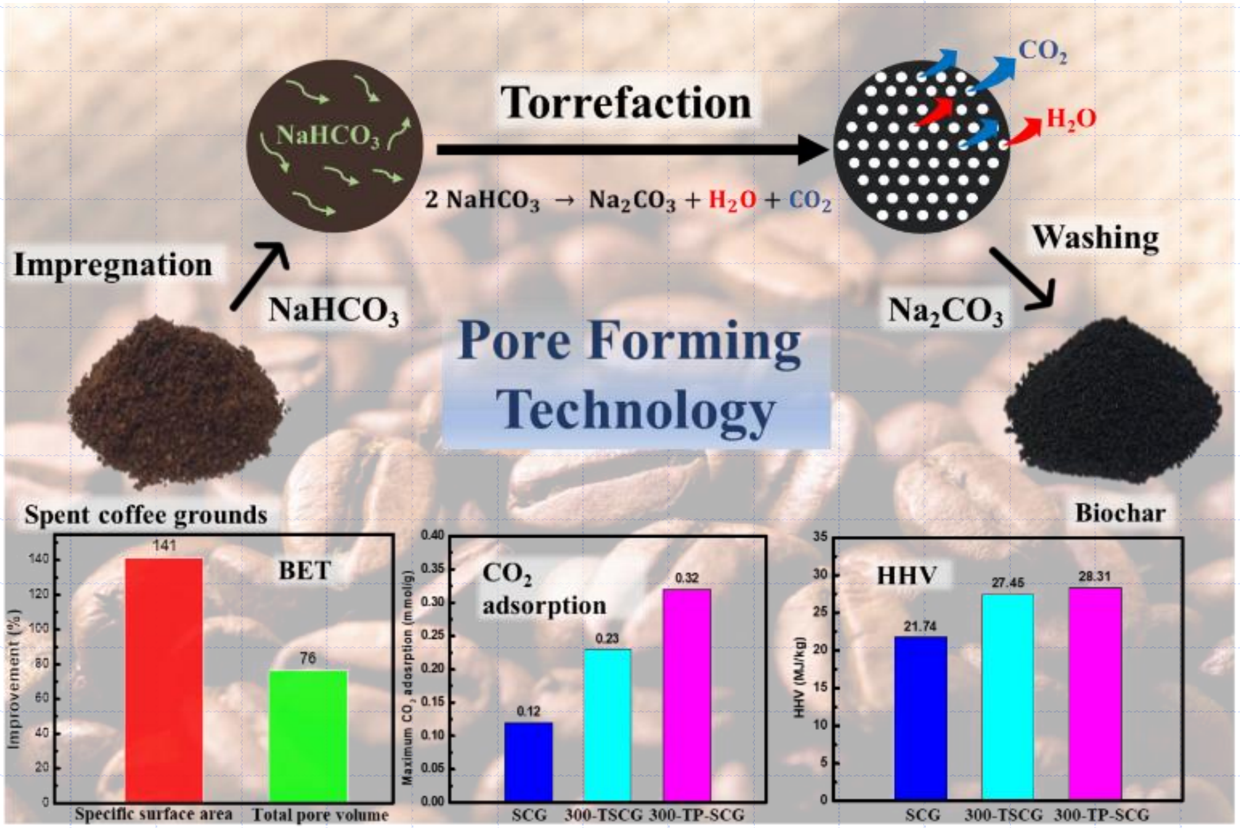


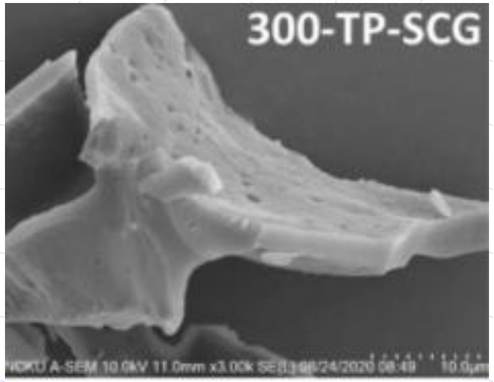



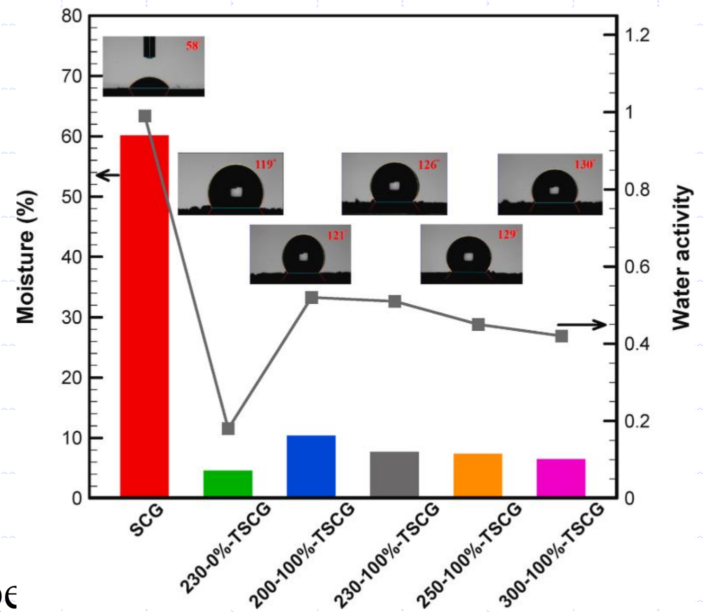




sodium bicarbonate

300-TP-SCG/300-TSCG

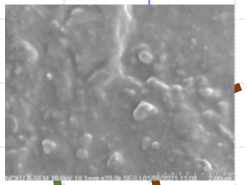
Torrefaction without $H_2O_2$
230 °C, 30 min
23.32 $MJ \cdot kg^{-1}$



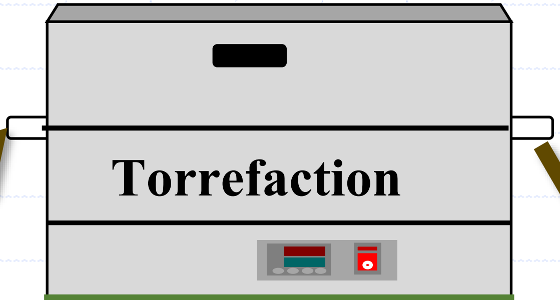

$MgCl_2$, $NaHCO_3$, NaCl, $H_3PO_4$, $FeCl_3$, $Fe(NO_3)_3$, KOH, $NaHCO_3$ & $CH_4N_2S$, NaOH

Green additive

$H_2O_2$
Hydrogen peroxide



Spent coffee grounds



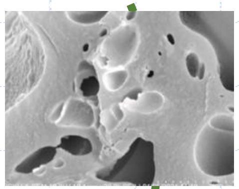
Torrefaction

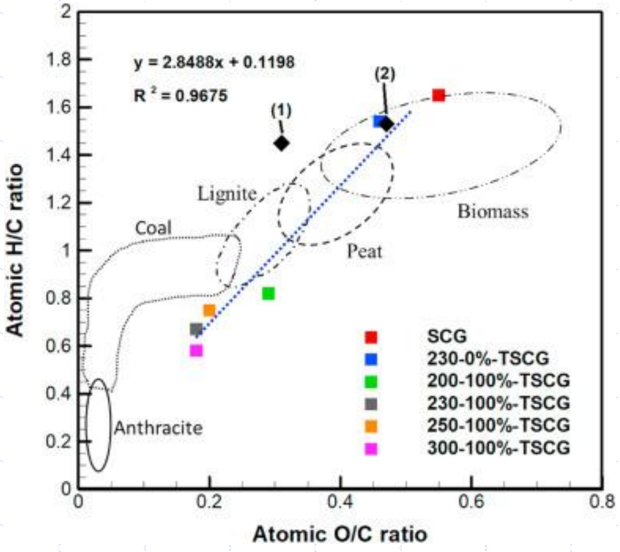
$$2H_2O_2 \rightarrow 2H_2O + O_2$$
$$H_2O_2 \rightarrow HO_2\bullet + H^+$$
$$H_2O_2 \rightarrow HO\bullet + OH^-$$

Calorific Value-Upgrading Technology

- Solid fuel
- Pollutant adsorbe
- Soil amendments

Biochar



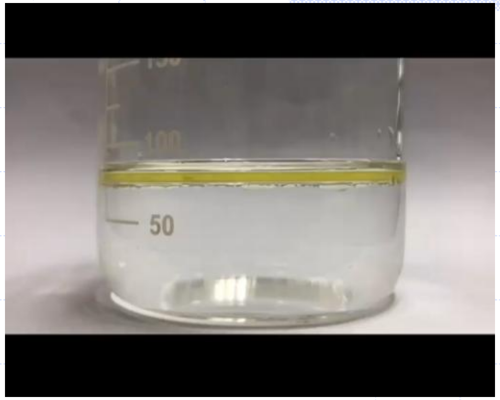


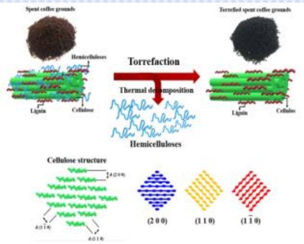

HHVs: 21.97 $MJ \cdot kg^{-1}$
Bulk density: 0.42 $g \cdot cm^{-3}$
Water activity: 0.99

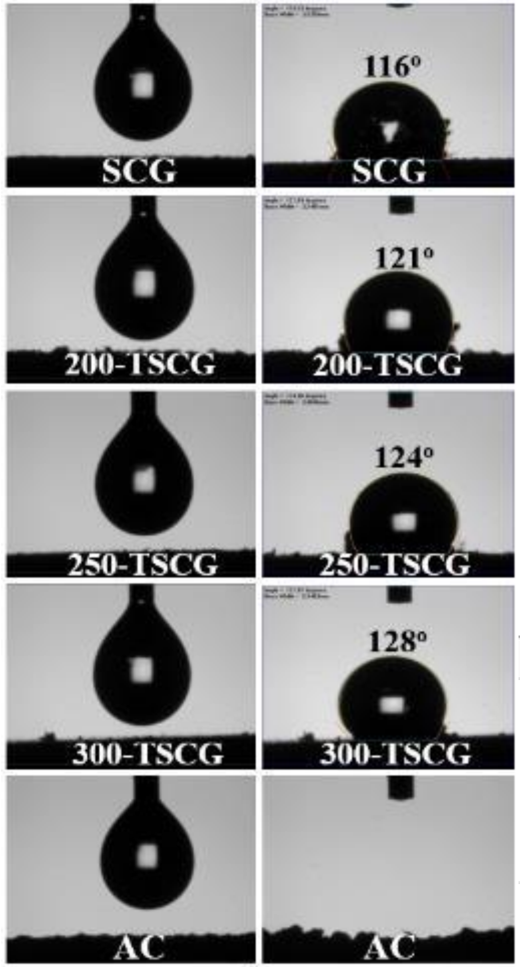
HHVs: up to 27.00 $MJ \cdot kg^{-1}$
Bulk density: 0.12 $g \cdot cm^{-3}$
Water activity: 0.51 (< 0.6)

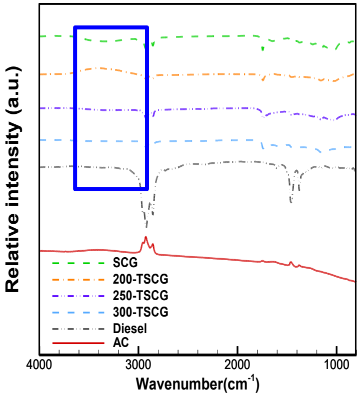
Pollution

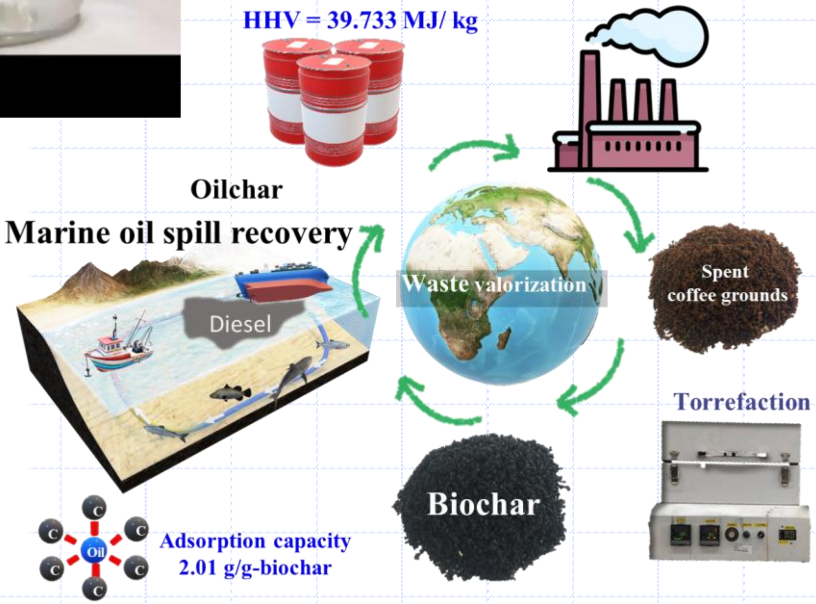
Recycled resources

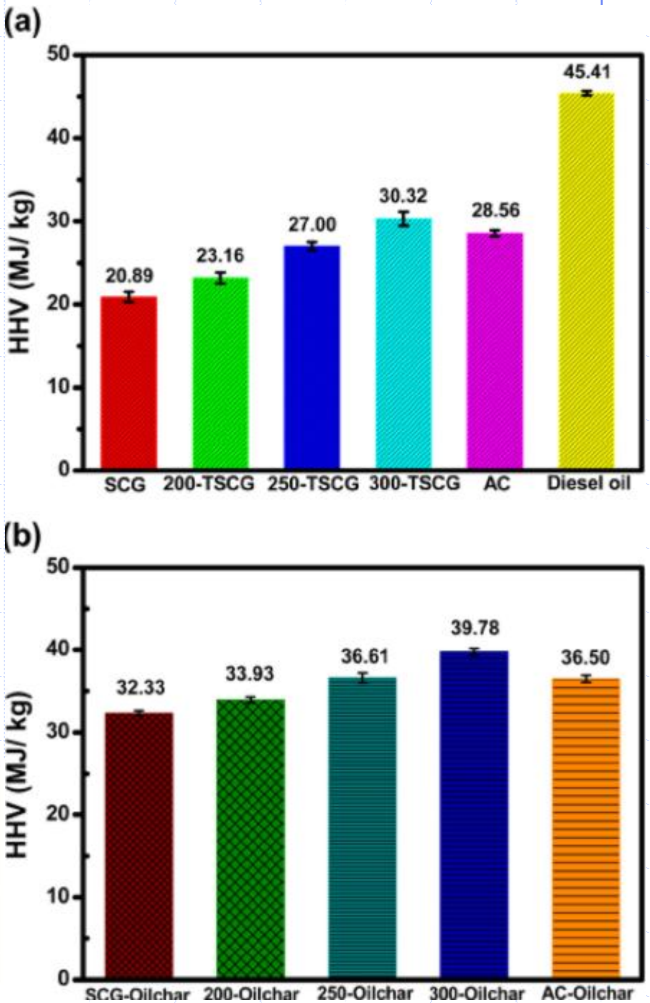


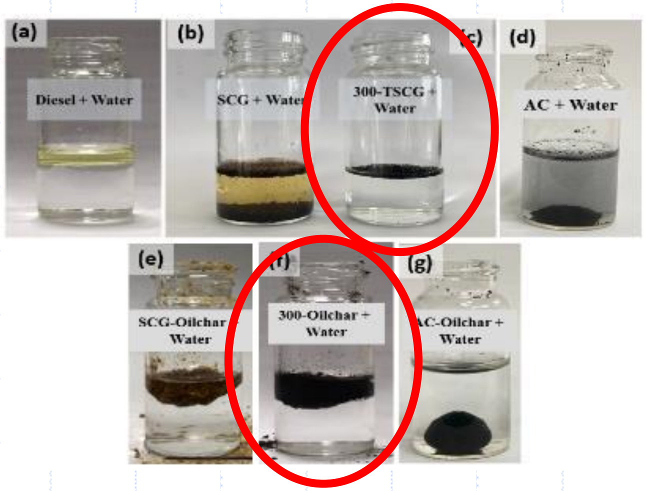




| Material | Adsorption capacity (g $g^{-1}$) |
|---|---|
| SCG | 1.02 |
| 200-TSCG | 1.10 |
| 250-TSCG | 1.25 |
| 300-TSCG | 1.50 |
| AC | 1.10 |



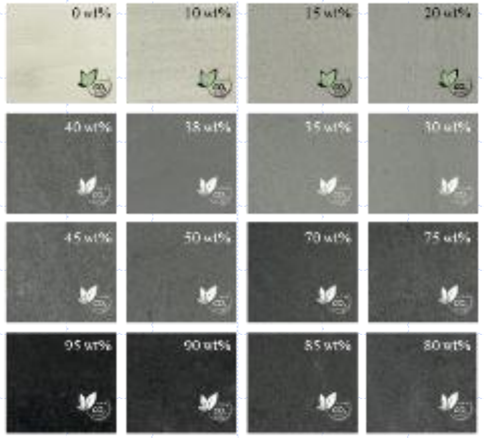

Hydrophobic & lipophilic

# Biochar for Architecture Coatings

**Hygroscopic sawdust biochar**

| Architectural Coatings | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biochar (wt%) | 0 | 10 | 15 | 20 | 30 | 35 | 38 | 40 | 45 | 50 | 70 | 75 | 80 | 85 | 90 | 95 |
| CO2 sequestration (kg/kg Coatings) | 0 | 0.23 | 0.43 | 0.59 | 0.71 | 0.85 | 0.96 | 1.06 | 1.14 | 1.22 | 1.71 | 1.93 | 2.06 | 2.14 | 2.34 | 2.45 |
| Adhesion | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Good | Poor | Poor | Poor | Poor | Poor |

**Architectural coating color card**



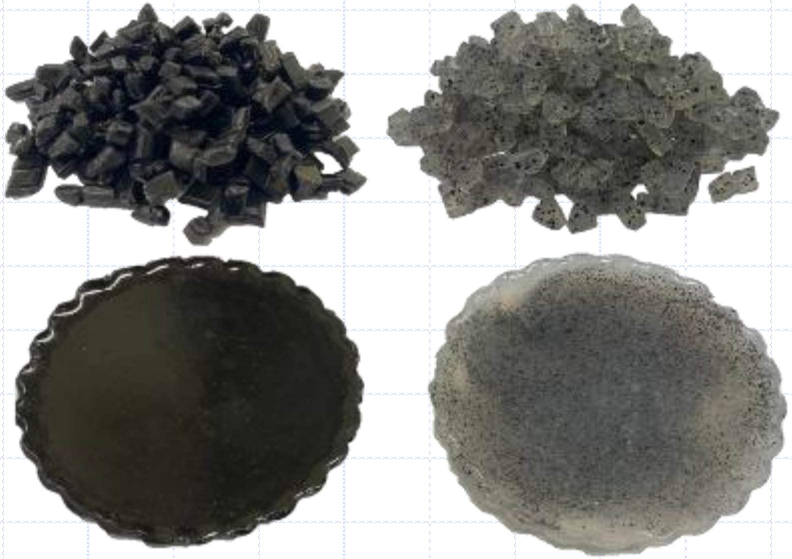

**Circular economy, Carbon sequestration, and Formaldehyde-free**

*High moisture absorption and adhesion, eliminate odor molecules from the air. The biochar is made from biomass waste and was applied to architectural coatings. Depending on the different amounts of biochar added, the architectural coatings can show different color changes.*


# Biochar for Plastic Masterbatch

- Dispersion
- Uniformity

**SCGs**




- Biochar amount & mechanical property

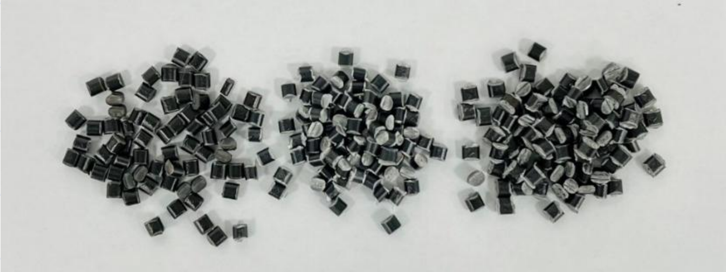
# Masterbatch

Torrefaction
300 ˚C

Polypropylene (PP)

Additive ratio: 1 & 2%

Particle size:
>25, 25-45, 45-200 μm

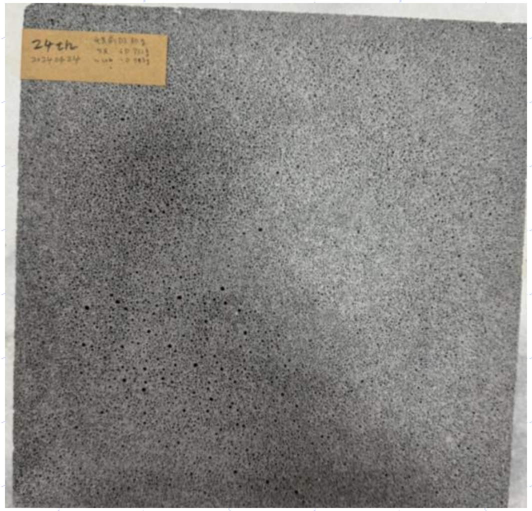




Effect of particle size and ratio of biochar pyrolyzed at 300 ˚C

| Formula | | 100% PP | 99% PP 1% biochar | 98% PP 2% biochar | 99% PP 1% biochar |
|---|---|---|---|---|---|
| particle size | um | - | 45-200 | 45-200 | >25 |
| M.I. | g/10min | 10.1 | 10.1 | 10.2 | 10.1 |
| T.S. | kg/cm² | 221 | 219 | 221 | 210 |
| Elongation at Break | % | 800 | 800 | 800 | 800 |
| F.S. | Kg/cm² | 10,201 | 9,311 | 10,014 | 9,806 |
| Hardness | R-scale | 76 | 54 | 54 | 52 |
| IZOD impact strength (23℃) | kg-cm/cm | 50 | 12 | 10 | 40 |
| HTD | ℃ | 110 | 104 | 103 | 101 |
| Lateral, longitudinal contraction rate | % | 1.3/1.3 | 1.3/1.3 | 1.3/1.3 | 1.3/1.3 |

Abbreviations:
M.I. – Mechanical Impact
T.S. – Tensile Strength
F.S. – Flexural Strength
HTD – Heat Transfer Deterioration

# Insulation Bricks

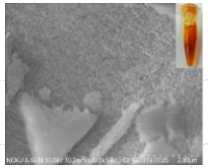


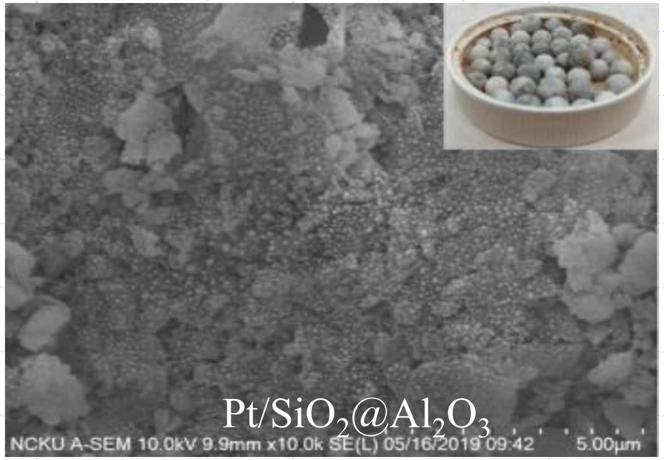
Biochar 9 wt%
size > 0.5 mm

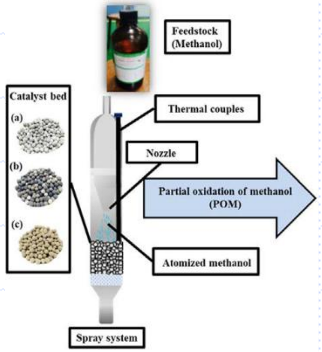
Biochar 9 wt%
size 0.25 mm ~ 355 μm

Biochar 9 wt%
size < 150 μm

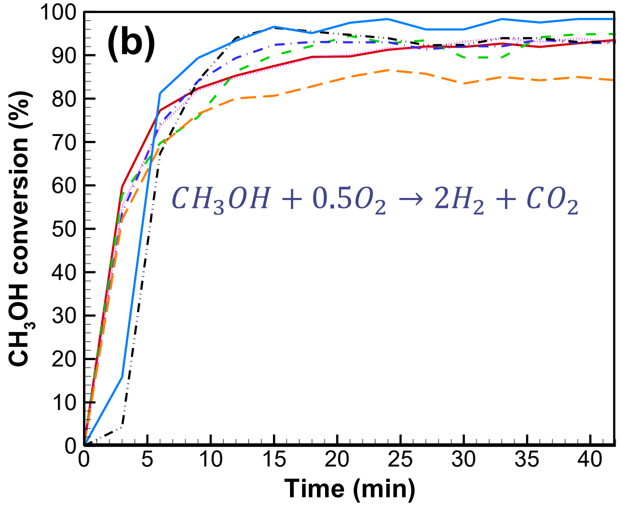
# Catalyst Preparation using TLPs

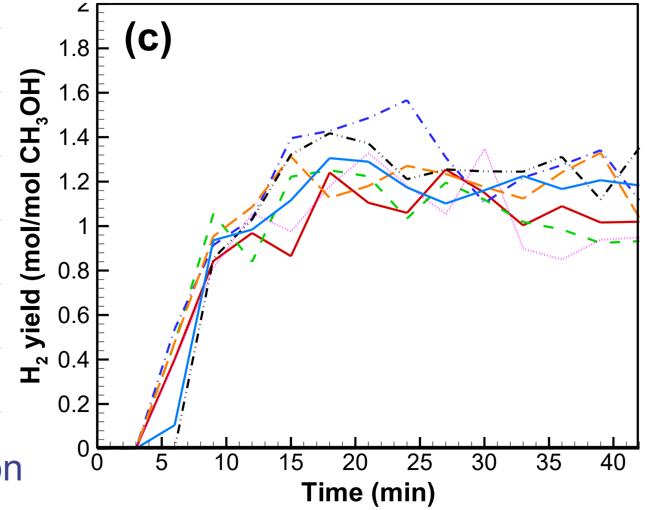





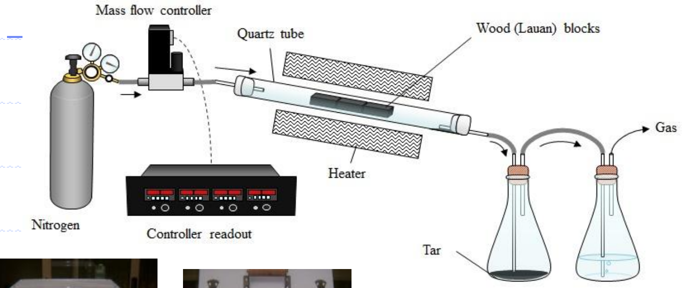

Methanol Partial Oxidation



# Reactor

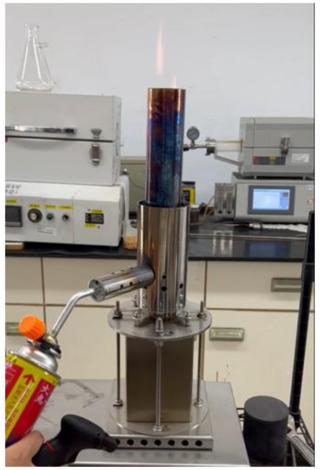
## 10 g-Scale



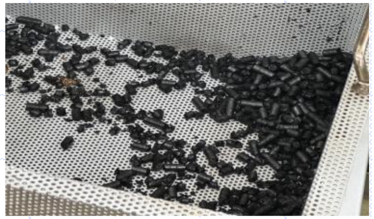

## 100 g-Scale

(a)

(b)



## 10 kg-Scale



## 100 kg-Scale

## 15 ton-Scale

# 2 ton-Scale Bamboo Biochar Production

# Soil Application (Fountain Grass)

Yield per unit area ($kg/m^2$)

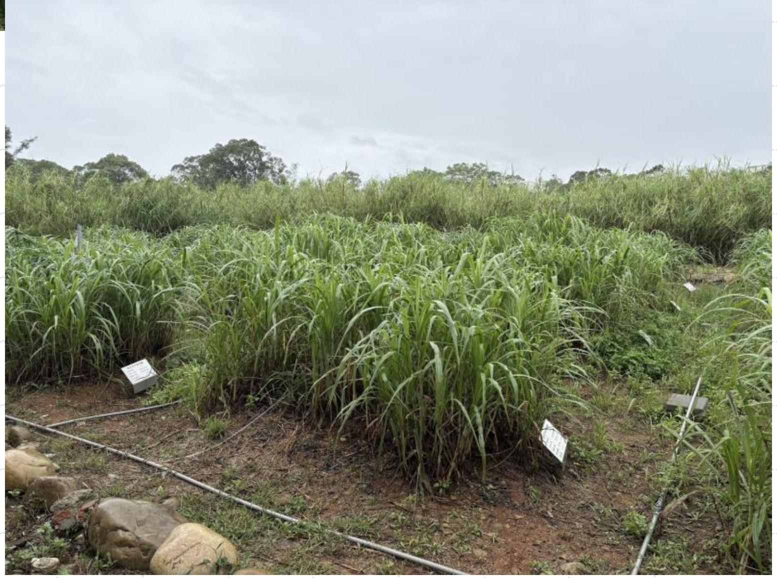
T1 Blank: **3.13**

T5 BSF + biochar: **7.09**

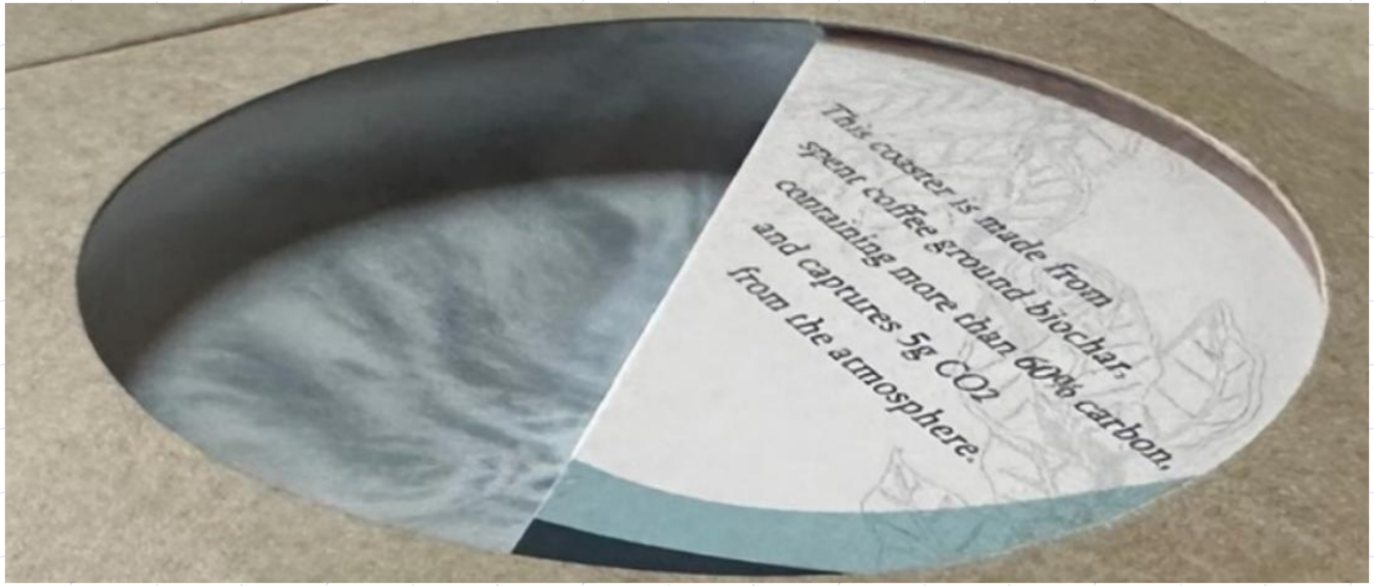
T7 YM fertilizer + biochar: **6.35**

Biochar (**38** ton $CO_{2e}$/ha/year)

# Natural Carbon Sink Monitoring System

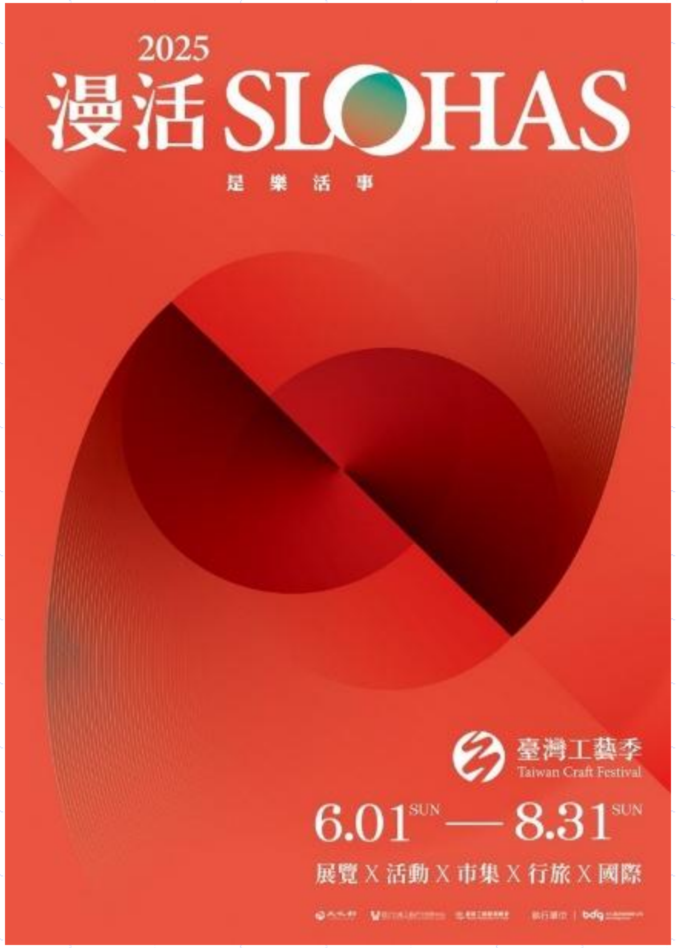


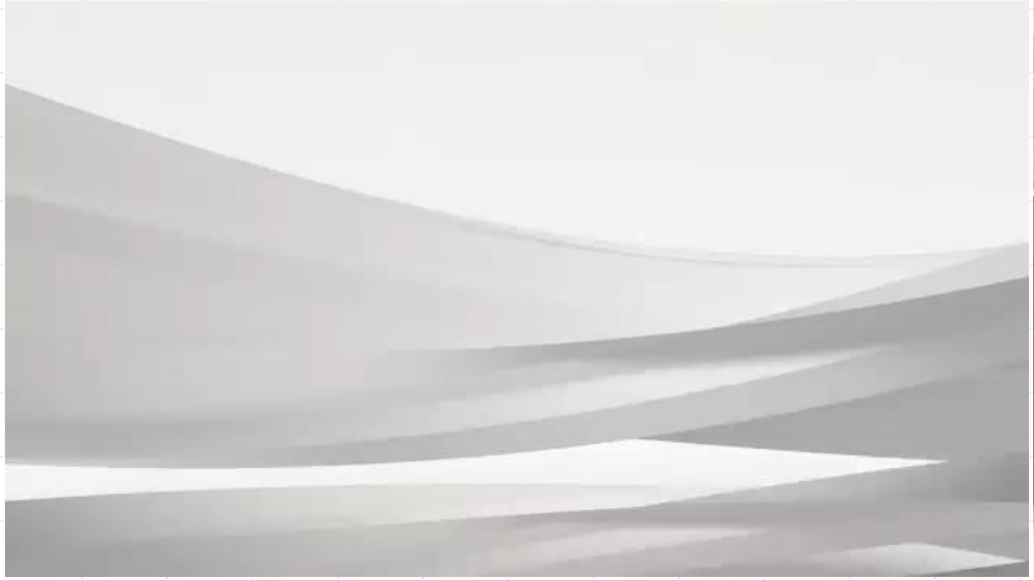
# Soil Application (Taiwan Acacia)

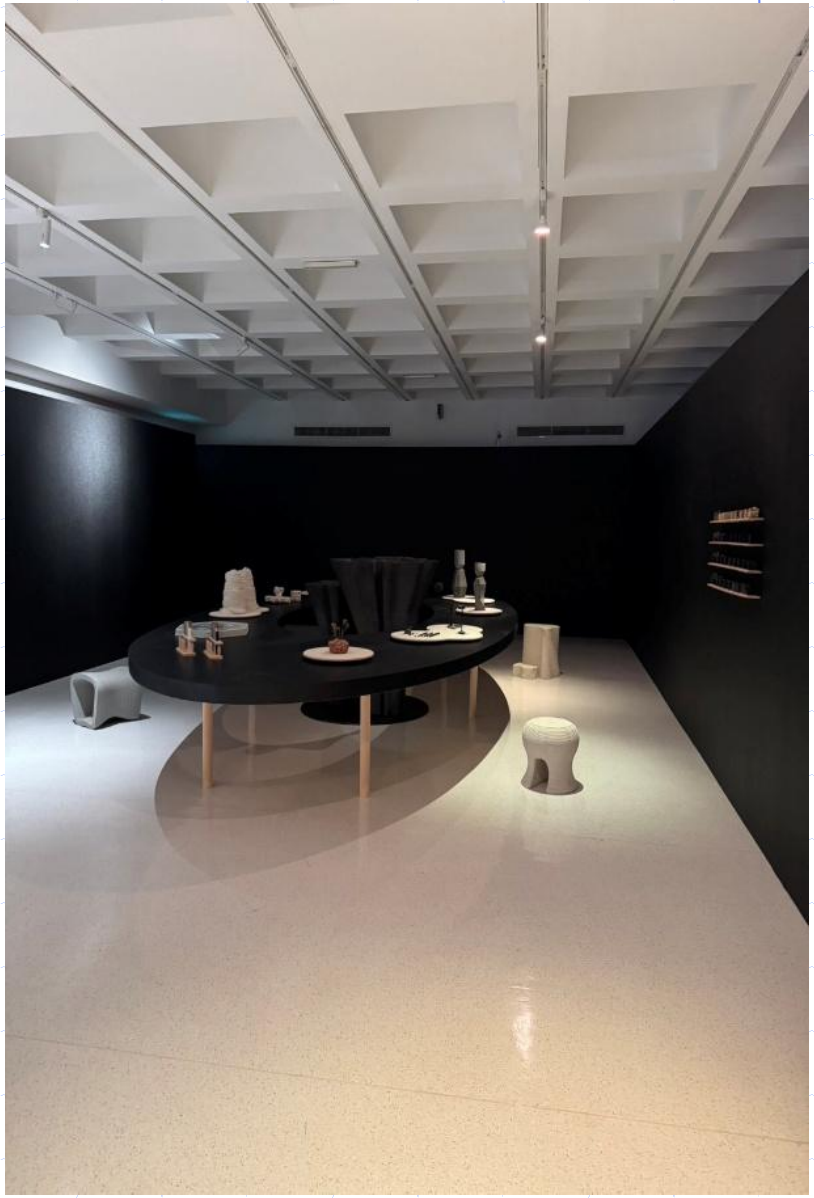

This coaster is made from
spent coffee ground biochar,
containing more than 60% carbon,
and captures 5g CO2
from the atmosphere.

HHTD25
Accelerating Imagination

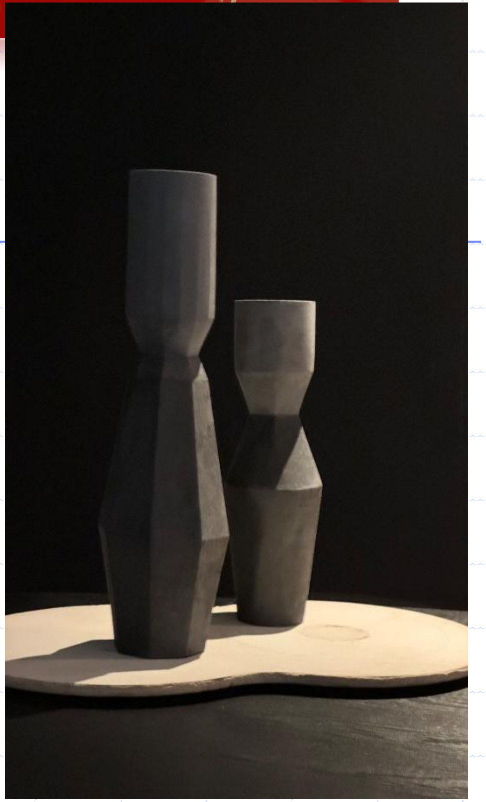
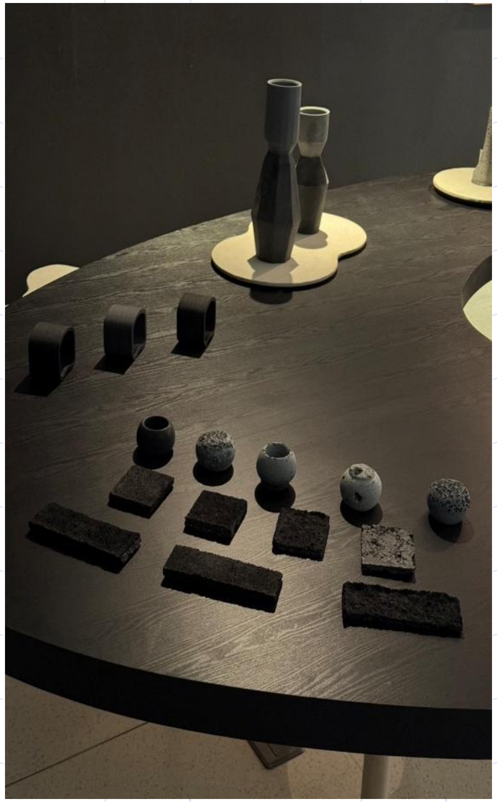
FOXCONN
鴻海科技集團



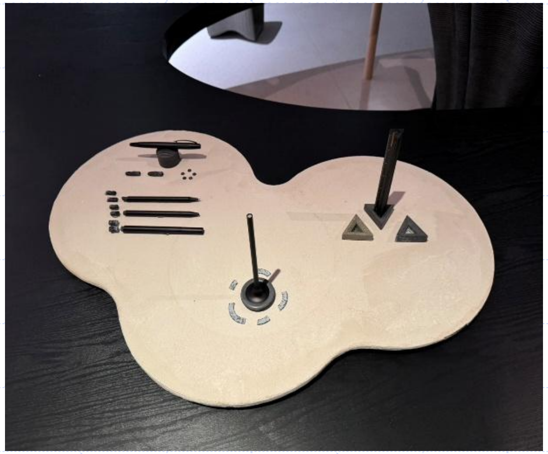





- 簡單（Simplicity）
- 生活型態（Lifestyle）
- 原創（Originality）
- 健康（Health）
- 美學（Aesthetics）
- 永續（Sustainability）

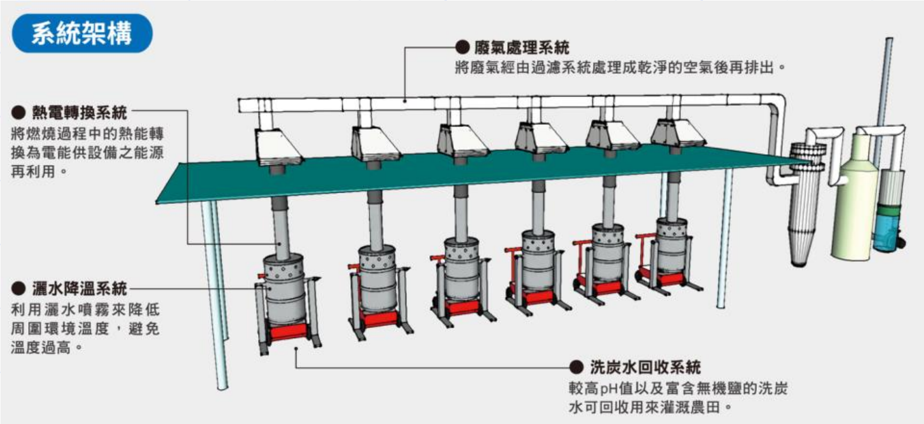



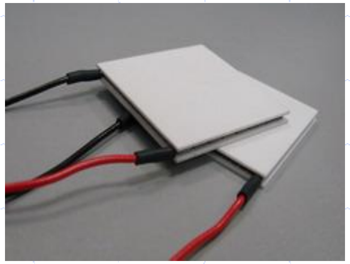


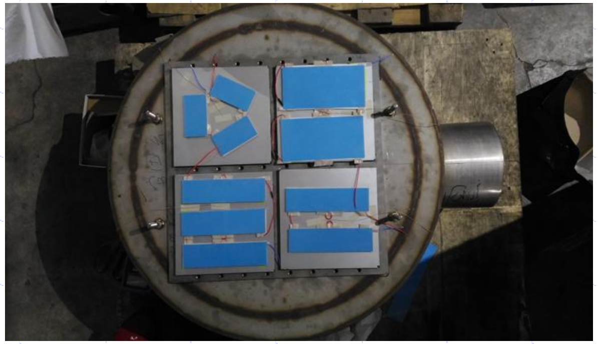


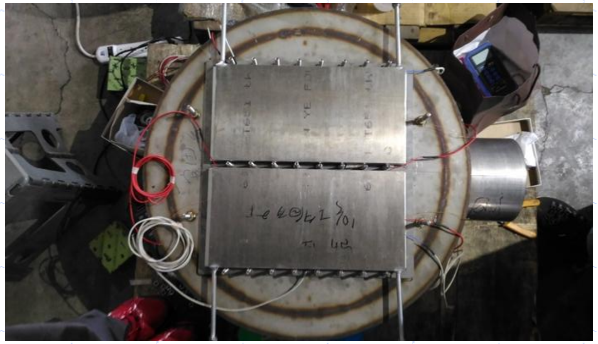

# System Integration

# Combination of Biochar Production and Thermoelectric Generation

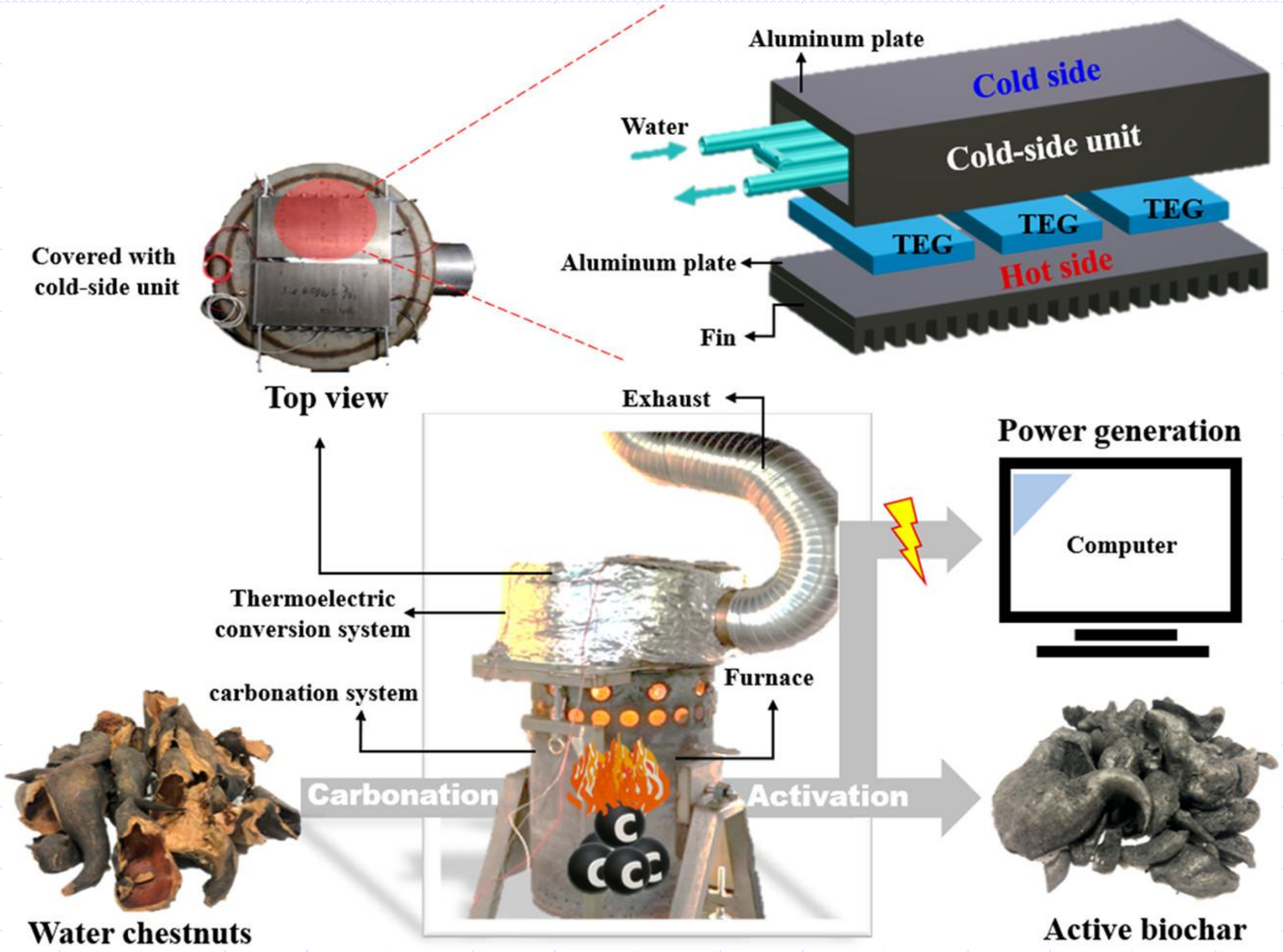


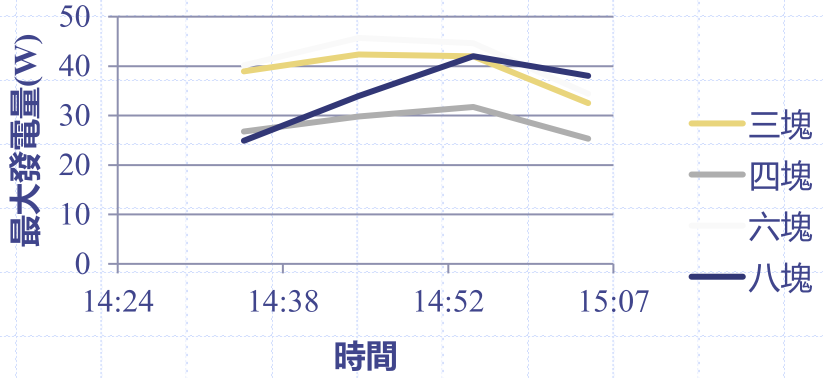


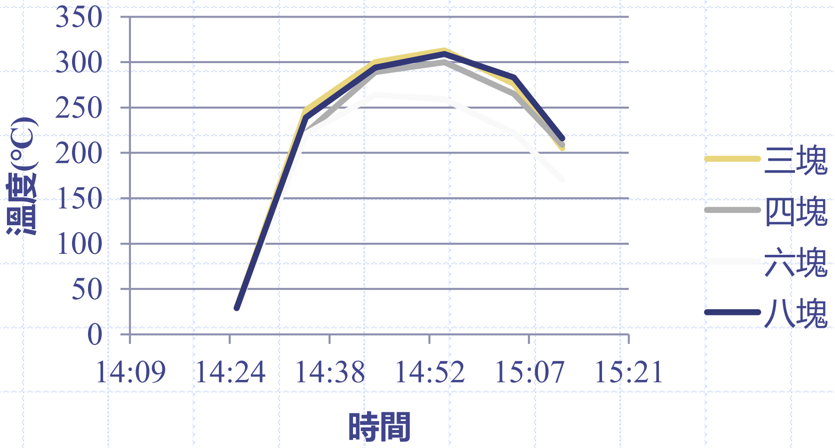


# Combination of Biochar Production and Thermoelectric Generation

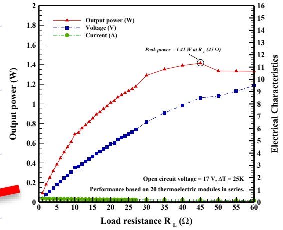


# Combination of Biochar Production and Thermoelectric Generation

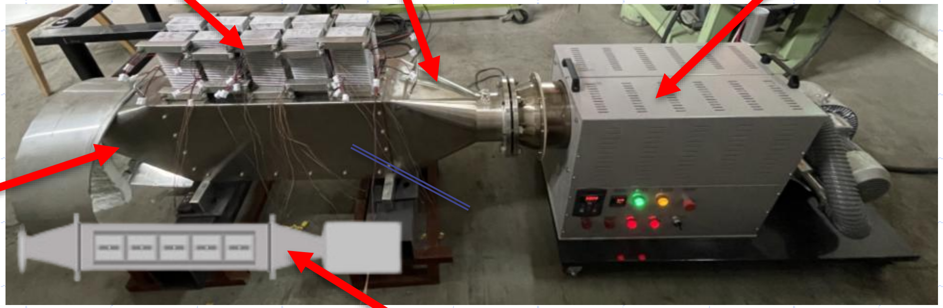
# Combination of Biochar Production and Thermoelectric Generation




C: TEG System

B: Flue Duct Wall

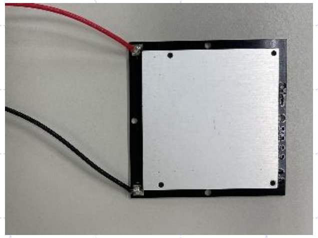
A: Heat Source Module



D: Exit

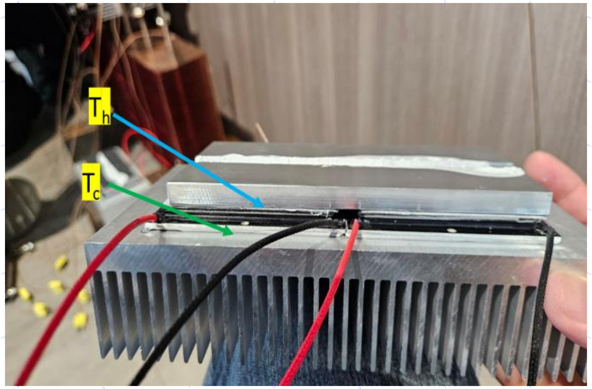
E: Top-View

$\Delta T = 25$



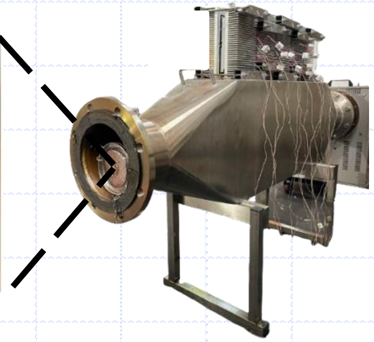
**Mean output power of installed TEGs 1.41 W (10 Ω)**

| | Bamboo | Coffee grounds |
|---|---|---|
| Solid yield | 32.20% | 23.40% |
| Energy yield | 41.21% | 32.74% |
| HHV | 19.30 → **24.70** | 18.80 → **26.31** MJ·kg$^{-1}$ |
| Fixed carbon | > 60% | > 60% |




Coffee Grounds

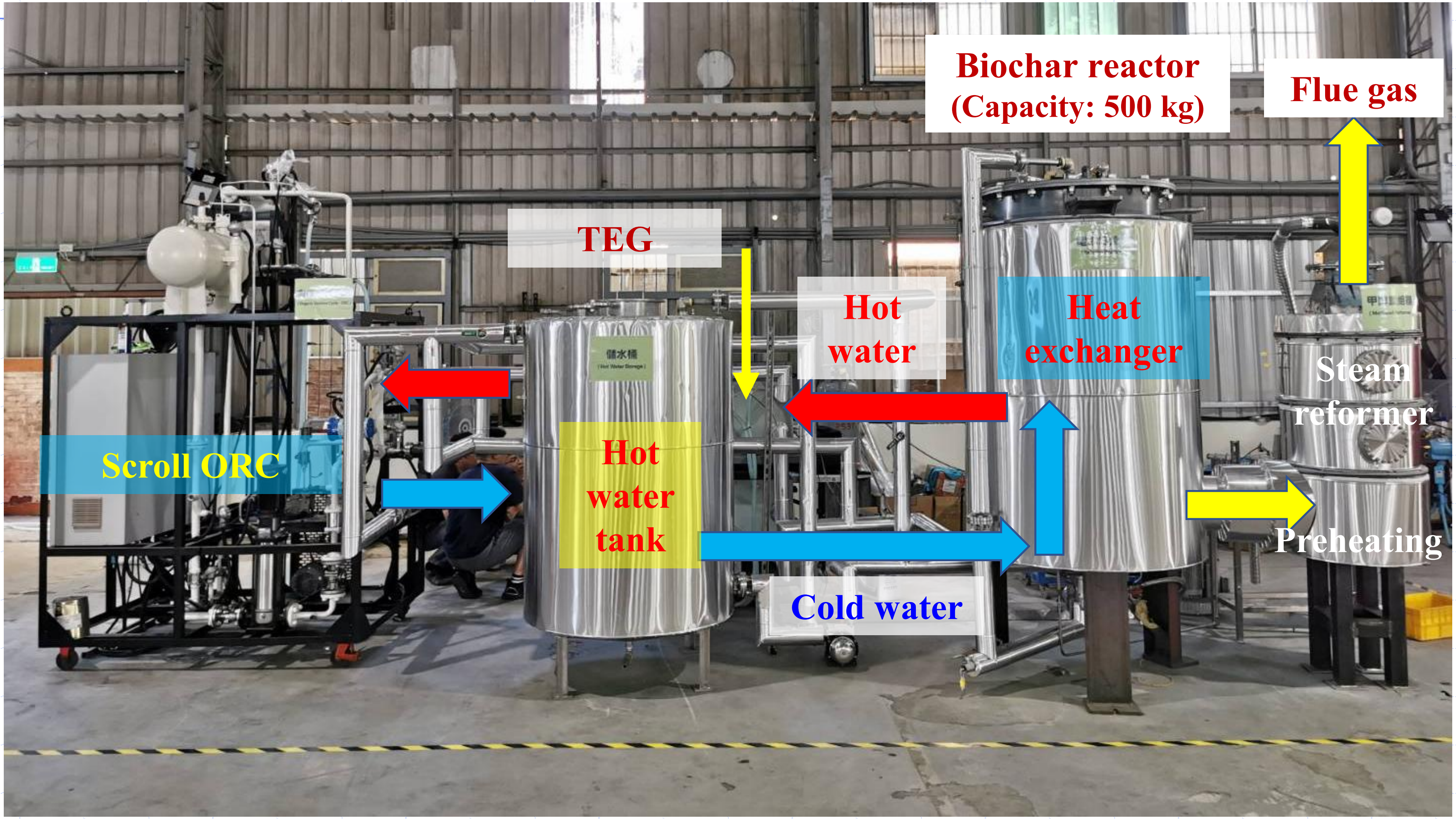
Bamboo



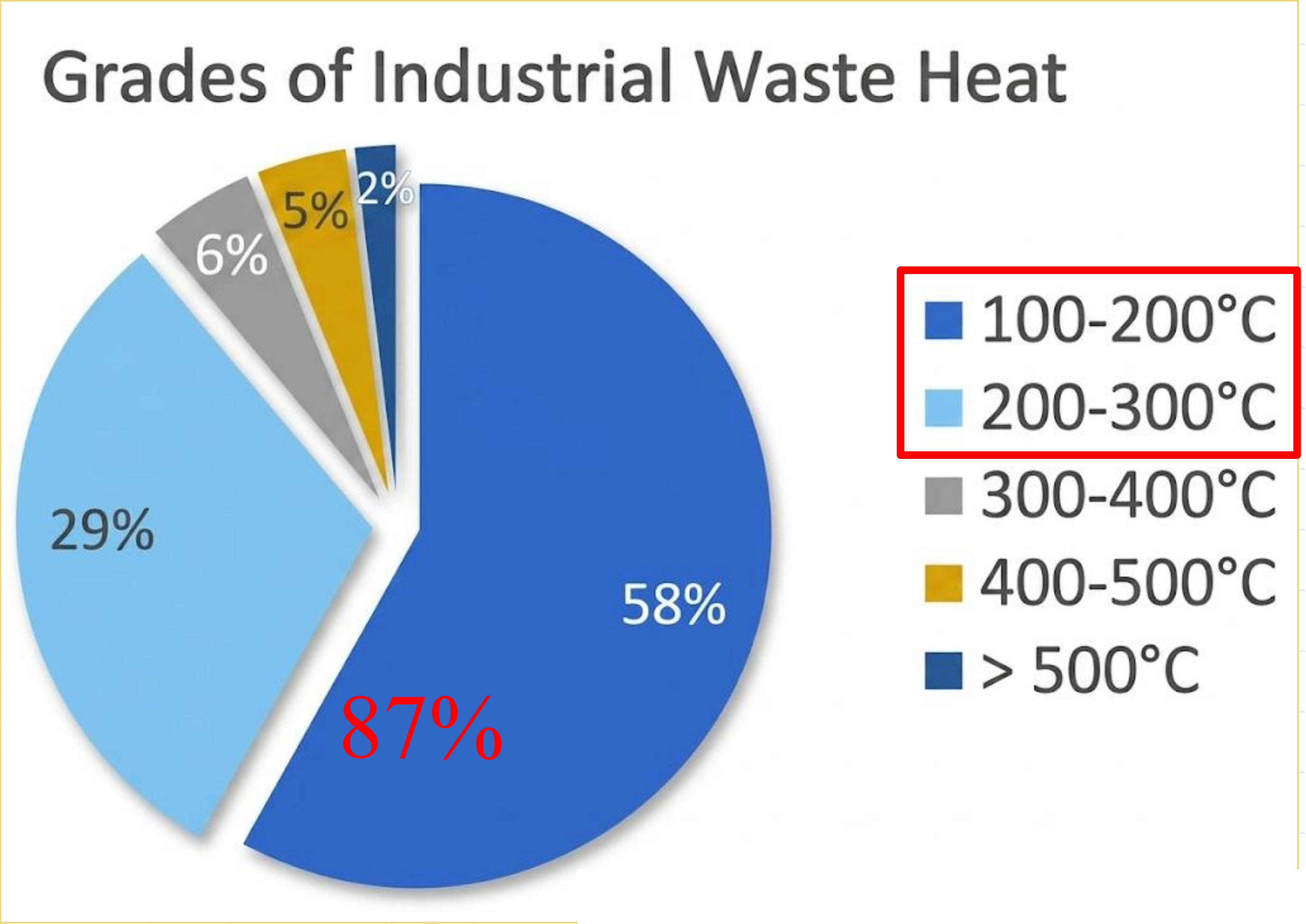
Outlet temperature: **693.15-723.15 K** (pyrolysis),Time: **30 min**

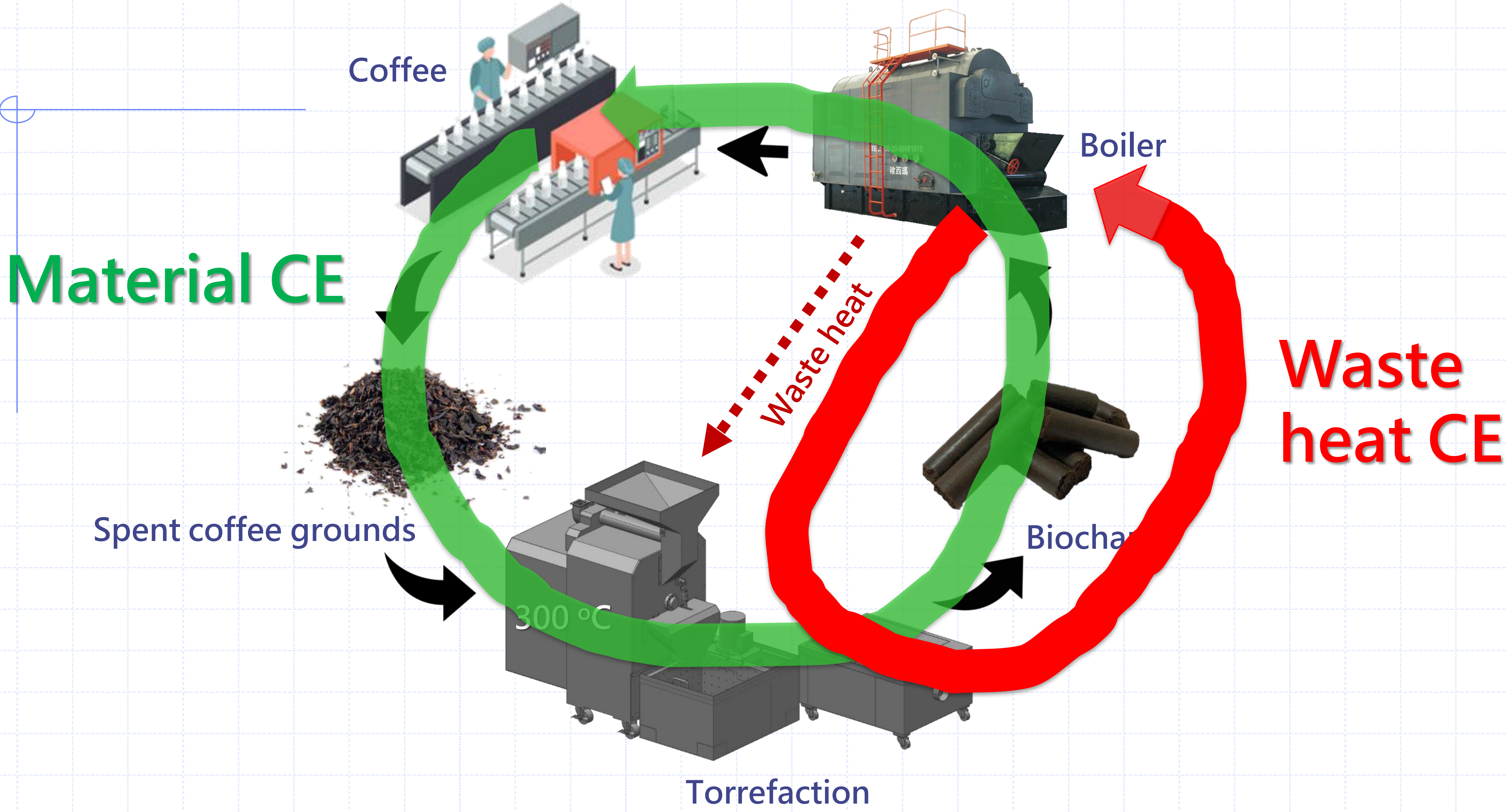
**35.2 % HHV improvement** **HHV= 26.3 MJ·kg$^{-1}$**

# 2nd Gen. Four-Stage Waste Herat Recovery



# Waste Heat Grades




Coffee
Boiler
Material CE
Waste heat
Waste heat CE
Spent coffee grounds
300 ºC
Biochar
Torrefaction

# Energy–Environment Nexus: Technologies for Clean Production and Storage

Participating journal: Discover Energy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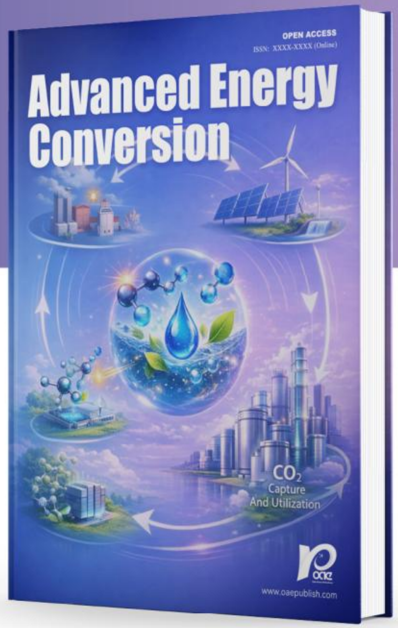


## Topics include

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- Waste-to-energy and circular economy
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