Carbon Dioxide Capture for Battery Electrode Production through Microalgae Cultivation and Pyrolysis

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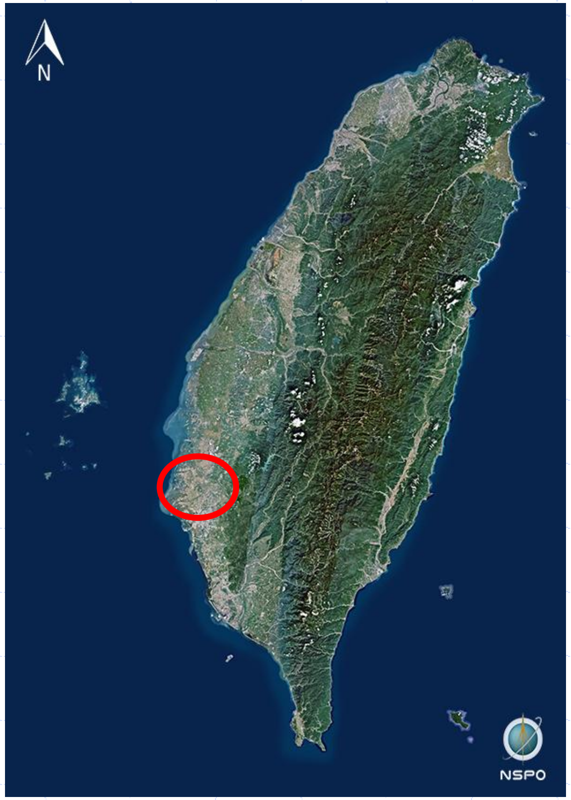
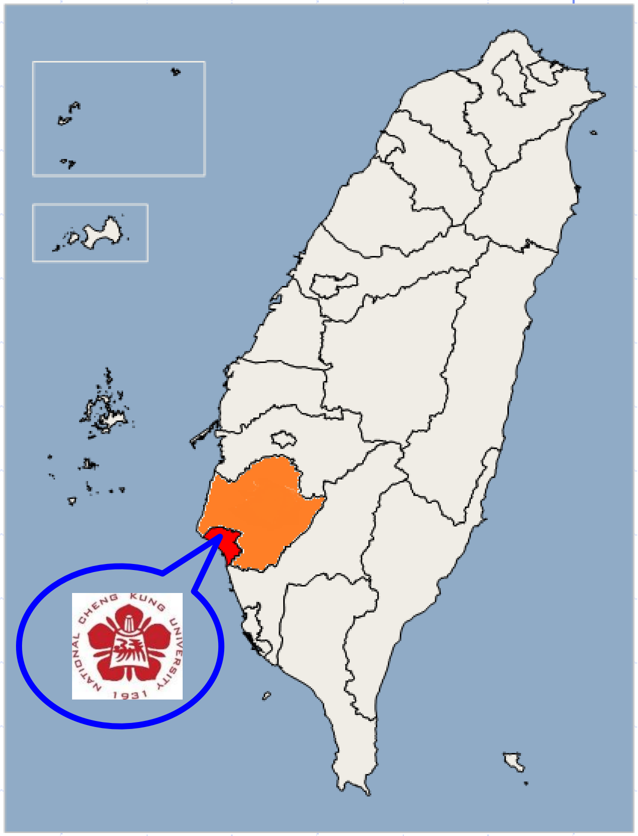
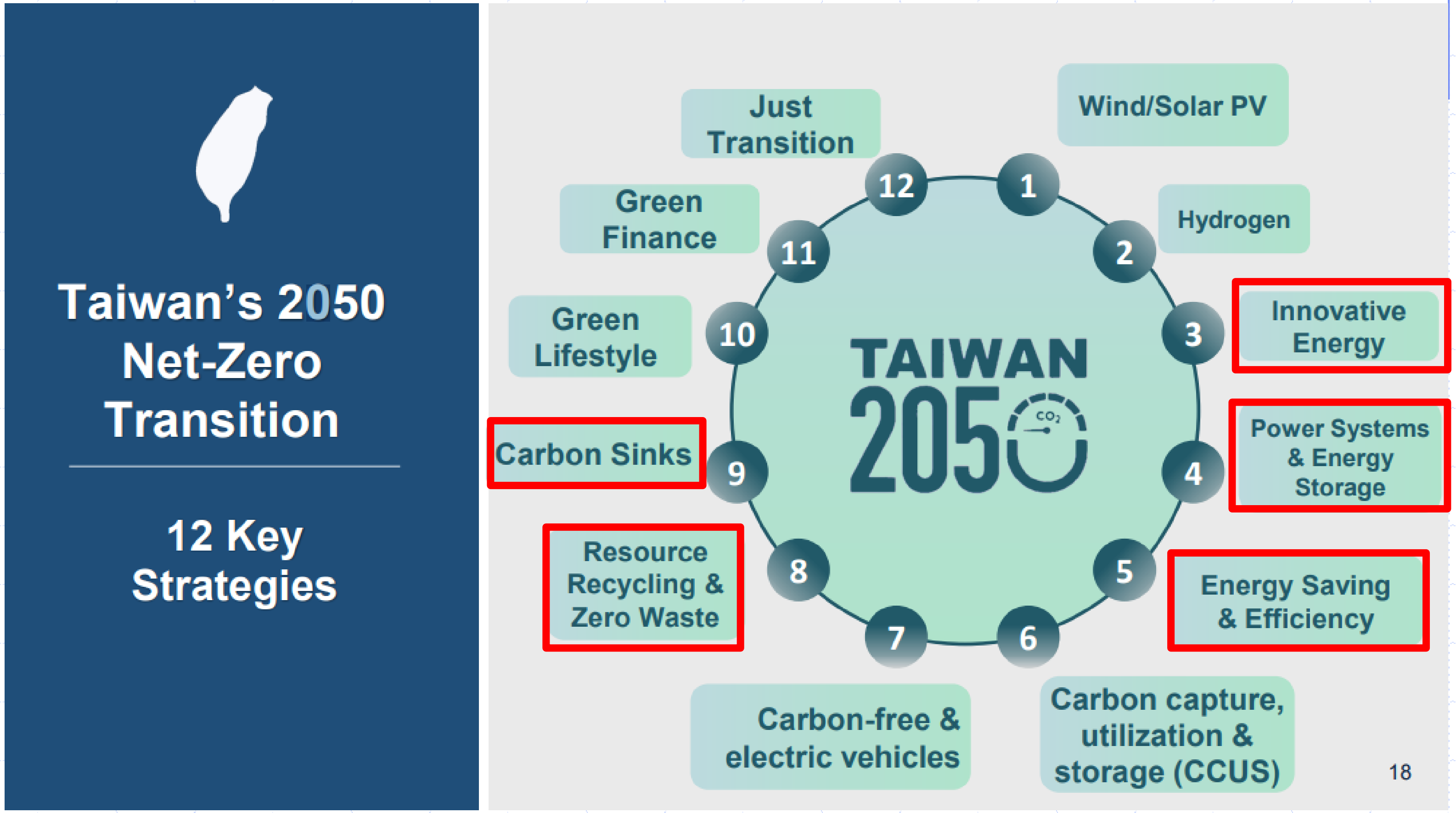




Background and Outline

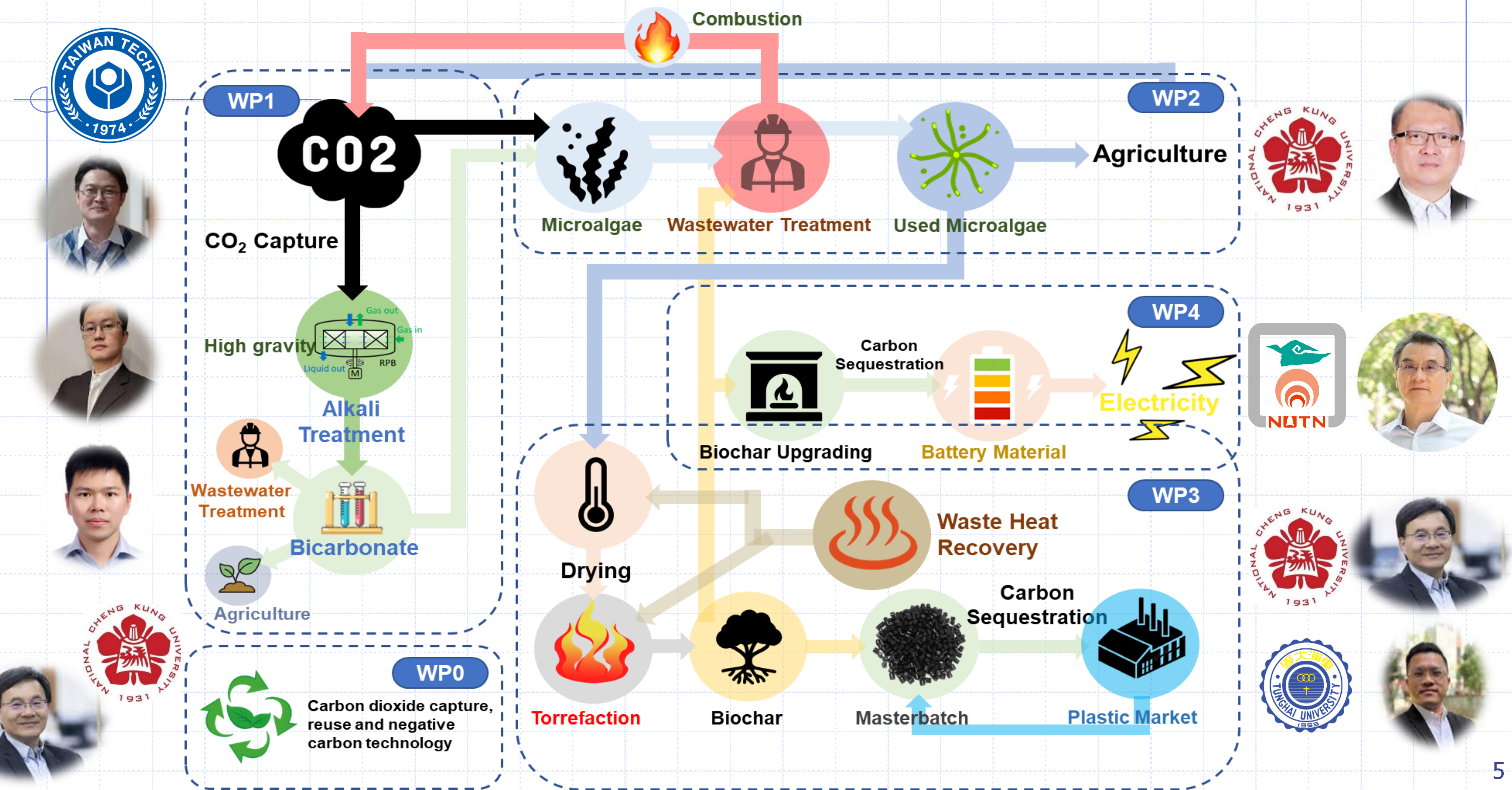
Taiwan is undertaking national-level Carbon Capture, Utilization, and Storage (CCUS) initiatives as part of its 2050 net-zero goals, focusing on both natural carbon sinks and industrial CCUS technologies.



Outline

- CO_2 capture
- Microalgae cultivation
- Drying and pyrolysis
- Lithium-ion battery negative electrode

Research Structure and Flowchart



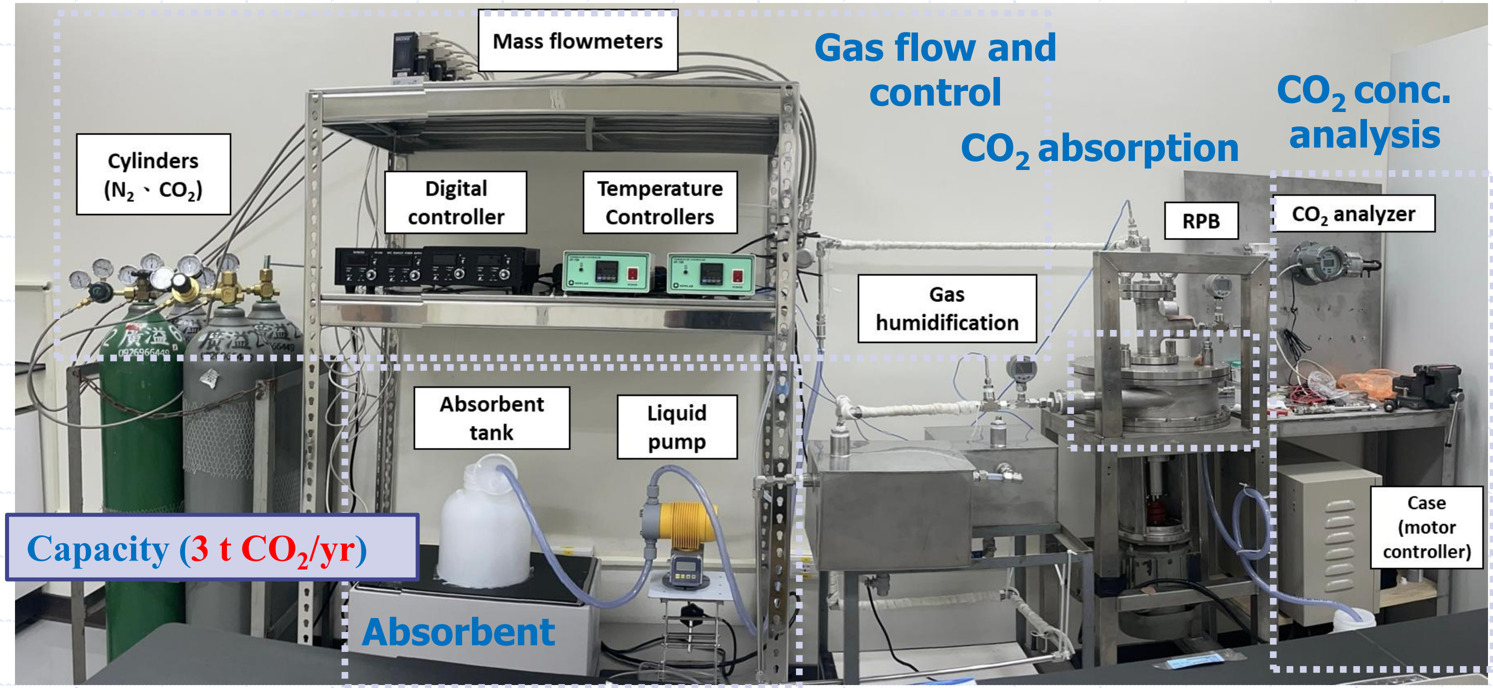
CO_2 Capture

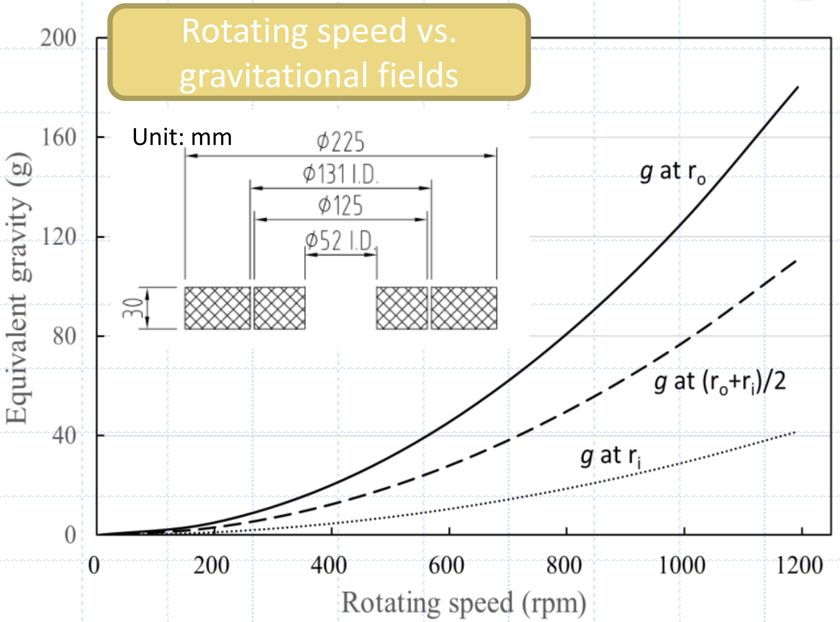
- CO_2 chemical absorption is the most mature post-combustion carbon capture technology before 2030 (TRL 9), with existing plants capturing 1.58 million metric tons of CO_2 per year. To improve efficiency, this study combines chemical absorption with process intensification technology (rotating packed bed).
    - To develop a 3-ton/year (lab-scale) carbon capture system in the 1st year.
    - Scale up the system to 30-ton/year (pilot-scale) in the 2nd year.
    - The solution containing carbonate/bicarbonate is used for microalgae cultivation.

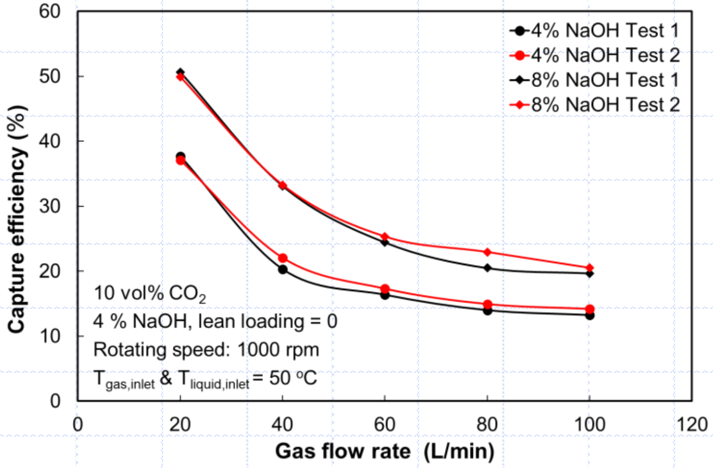
- RPB-based CO_2 capture process at Sinopec (30 k ton CO_2/yr).
- The volume, height, area, and cost of the RPB are respectively 20%, 5%、40% and 50% of a conventional packed bed.

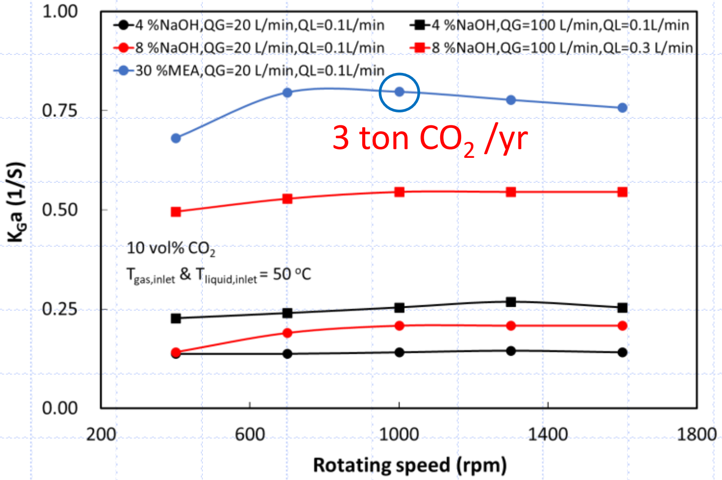
- RPB-based CO_2 capture process at China Steel Corporation (30 ton CO_2/yr).
- The volume of RPB is 1/3 of a conventional packed bed.

Lab-Scale CO_2 Capture System



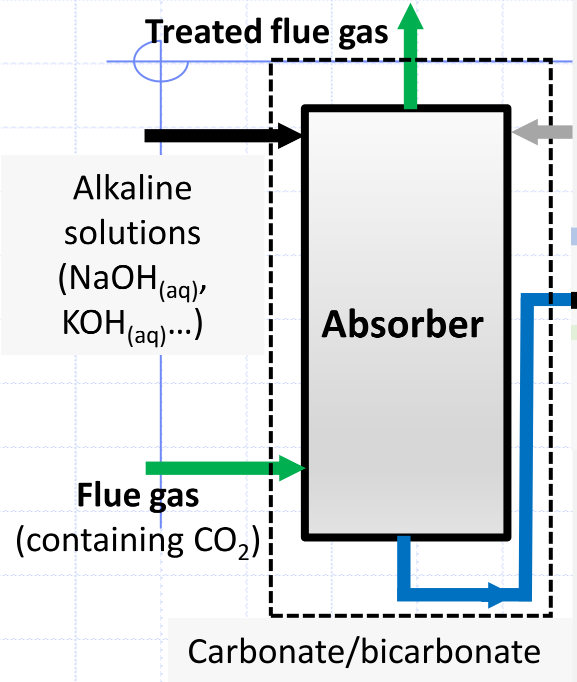




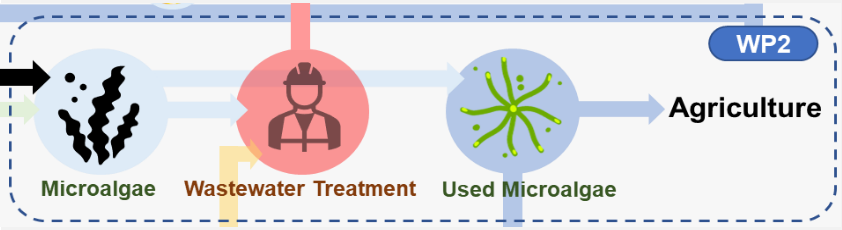


- The data is reproducible. The mean deviation of two individual experiments is less than 10%.
- 4% and 8% NaOH solutions are tested for the CO_2 capture performance.

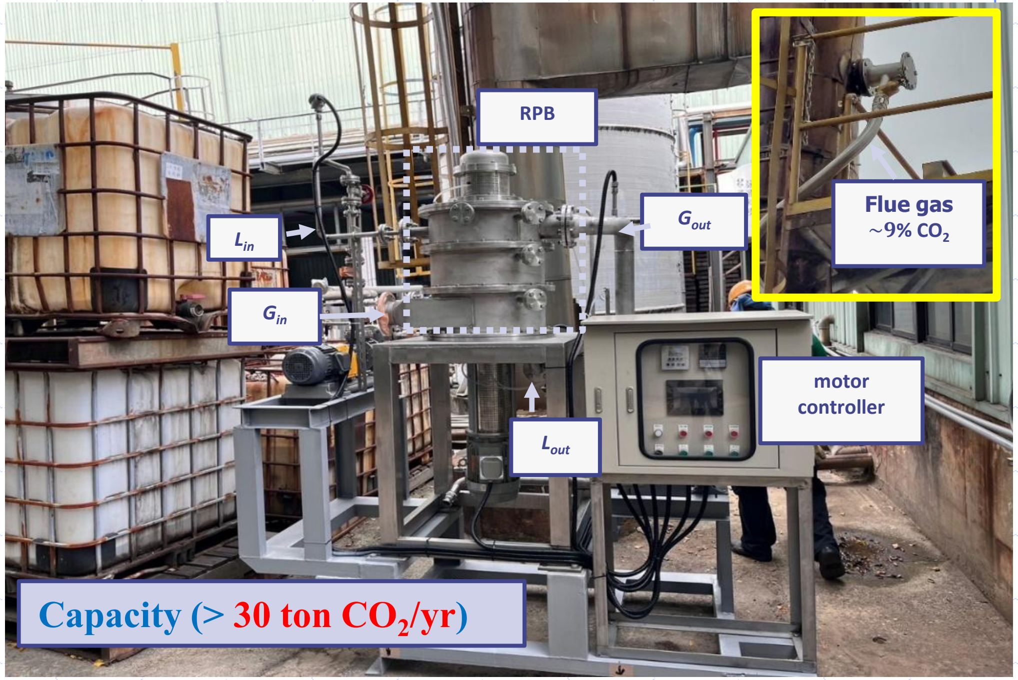
Pilot-Scale CO_2 Capture System



- ✓ No need of stripper
  →**lowering CAPX**
- ✓ No need of regeneration
  →**lowering OPEX**



- ✓ Use of microalgae
  →**Multiple utilization routes**
- ✓ Use of rotating paced bed (RPB)
  →**Further reduce CAPX of absorber**

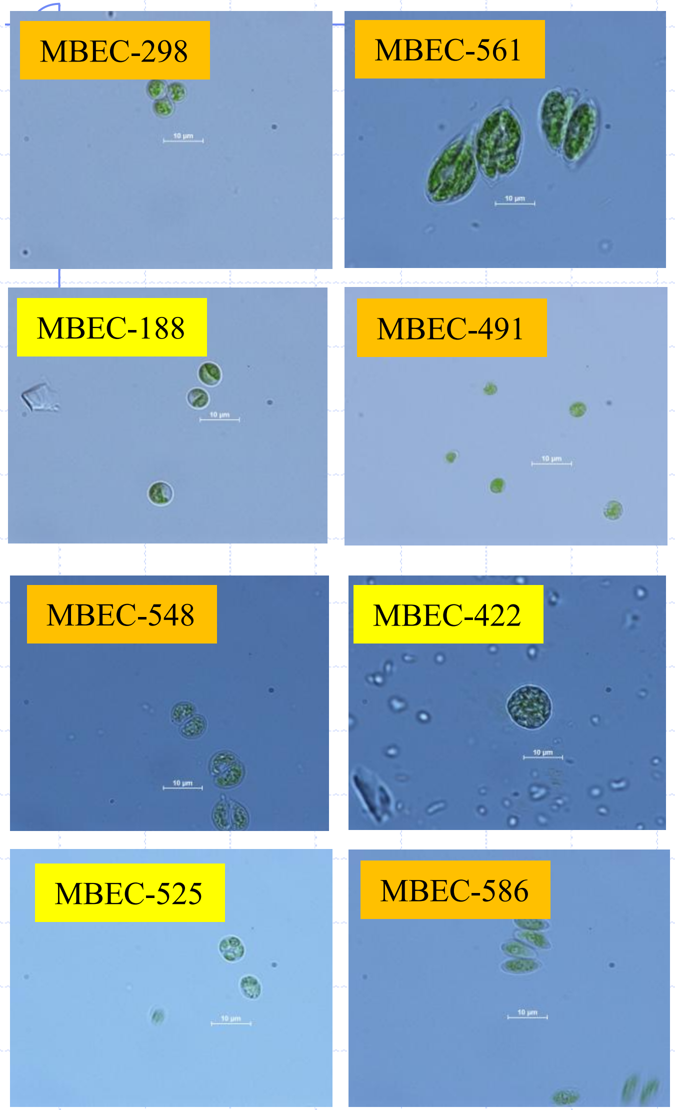


Baking Soda Cleaner

- Used NaOH solution to avoid energy-intensive regeneration processing.
- Captured bicarbonate/carbonate is reused as algae nutrients or made into baking soda cleaner.

Microalgae Species Selection for High CO_2 Tolerance

- Selected 8 target algae species from 598 algae species.



Microalgae	Colony	Biomass concentration (g/L)	Biomass productivity (g/L/d)	Carbon dioxide fixation rate (g/L/d)
MBEC-019	L	3.42	0.428	0.856
MBEC-065	M	2.16	0.270	0.540
MBEC-188	L	3.75	0.469	0.938
MBEC-191	L	3.38	0.423	0.846
MBEC-245	M	3.15	0.394	0.788
MBEC-298	M	2.47	0.309	0.618
MBEC-422	L	3.32	0.415	0.830
MBEC-491	L	3.63	0.454	0.908
MBEC-525	L	3.95	0.494	0.988
MBEC-548	M	3.17	0.396	0.792
MBEC-561	L	3.96	0.495	0.990
MBEC-586	M	3.11	0.389	0.778

Antifouling Coating of Zwitterionic Copolymer-Microalgae Cultivation

Applying double-ion materials can significantly reduce the attachment of microorganisms during microalgae cultivation or aquaculture processes, thereby effectively lowering operational costs

Using antifouling coatings made from zwitterionic copolymers as the material for microalgae bag-type photobioreactors has been proven to reduce the construction cost of microalgae cultivation equipment by at least 95%.

Microalgae Cultivation Reactor

Open pond

Biomass concentration：1.22 kg/ton
Protein content ： 54.6%
Lipid content ： 20.7%
Carbohydrate content ： 12.14%

Raceway

Biomass concentration：0.92 kg/ton
Protein content ： 46.5%
Lipid content ： 14.28%
Carbohydrate content ： 22.7%

Photobioreactor (PBR)

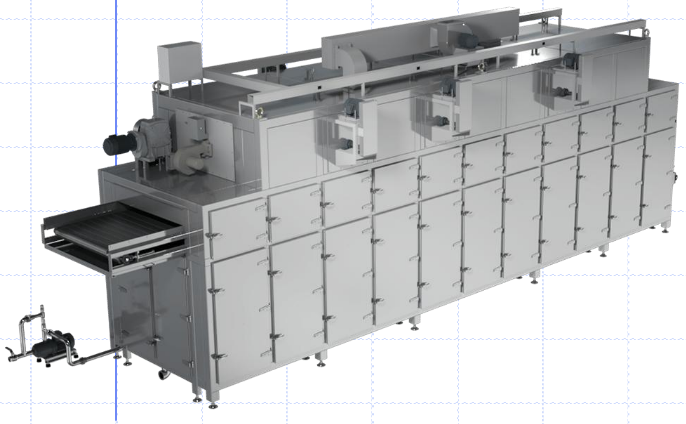
Biomass concentration：2.36 kg/ton
Protein content ： 37.5%
Lipid content ： 16.8%
Carbohydrate content ： 12.1%

Microalgae Drying

1. **Freeze-drying** is commonly used for microalgae, but it is a **energy-intensive** method among all industrial drying techniques.
2. **Thermal convection drying** is one of the most widely used commercial drying methods; however, when applied to microalgae, it **significantly reduces** their **quality**.
3. This subproject aims to utilize the **synergistic effect** between **discarded air filters** and **microalgae** to help **maintain a certain level of quality** even after thermal convection drying.

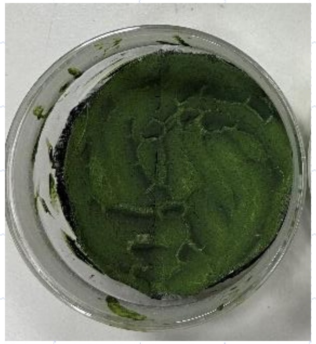
Thermal Convection Drying

1. Compared to freeze-drying, thermal convection drying requires less time, consumes less energy, and has a lower cost per unit of output.
2. The cost of freeze-drying is NTD 2,675 (US $90.15) per kilogram, whereas thermal convection drying costs only NTD 55 (US $1.85) per kilogram.



100 kg thermal convection dryer (continuous feeding possible)

20-30 kg freeze dryer



This subproject sample

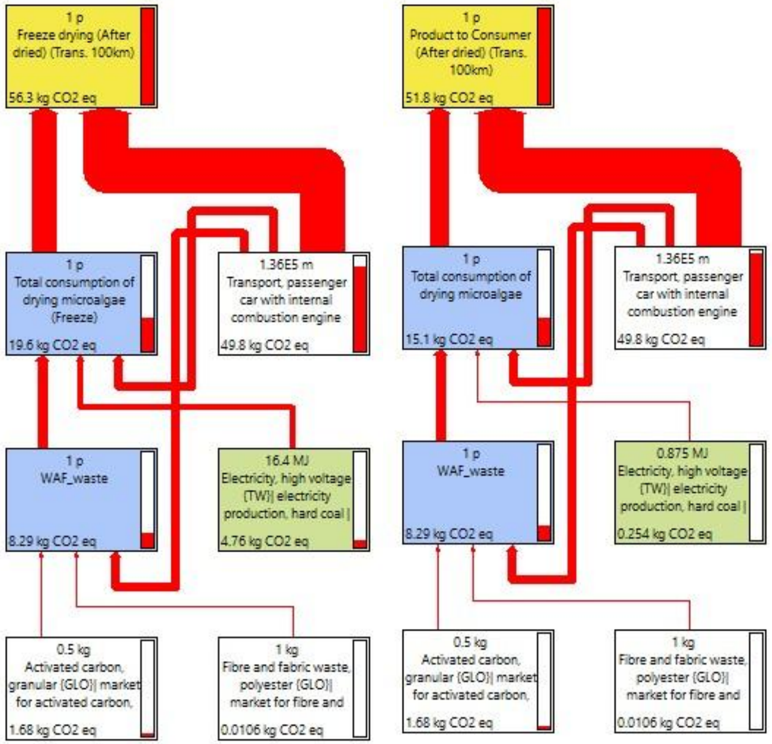
Freeze-drying sample

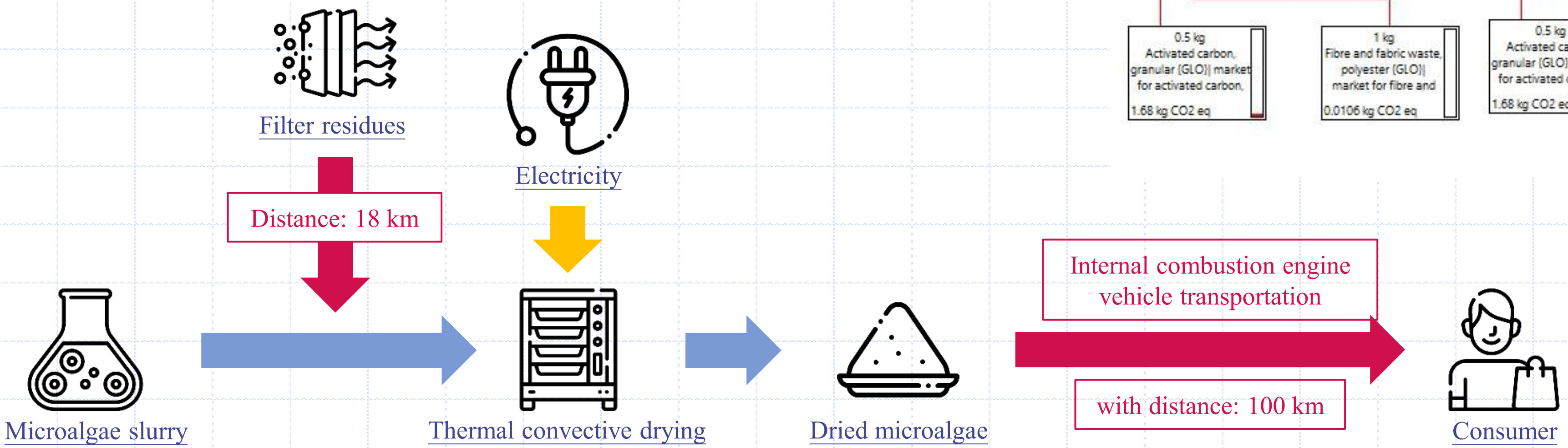
Ref：

1. https://www.tshs-dryer.com/zh-TW/Products/Multi-layers-Hot-Air-Dryer
2. 青蔥低溫低濕乾燥之研究，林佳穎，2010

Carbon Footprint

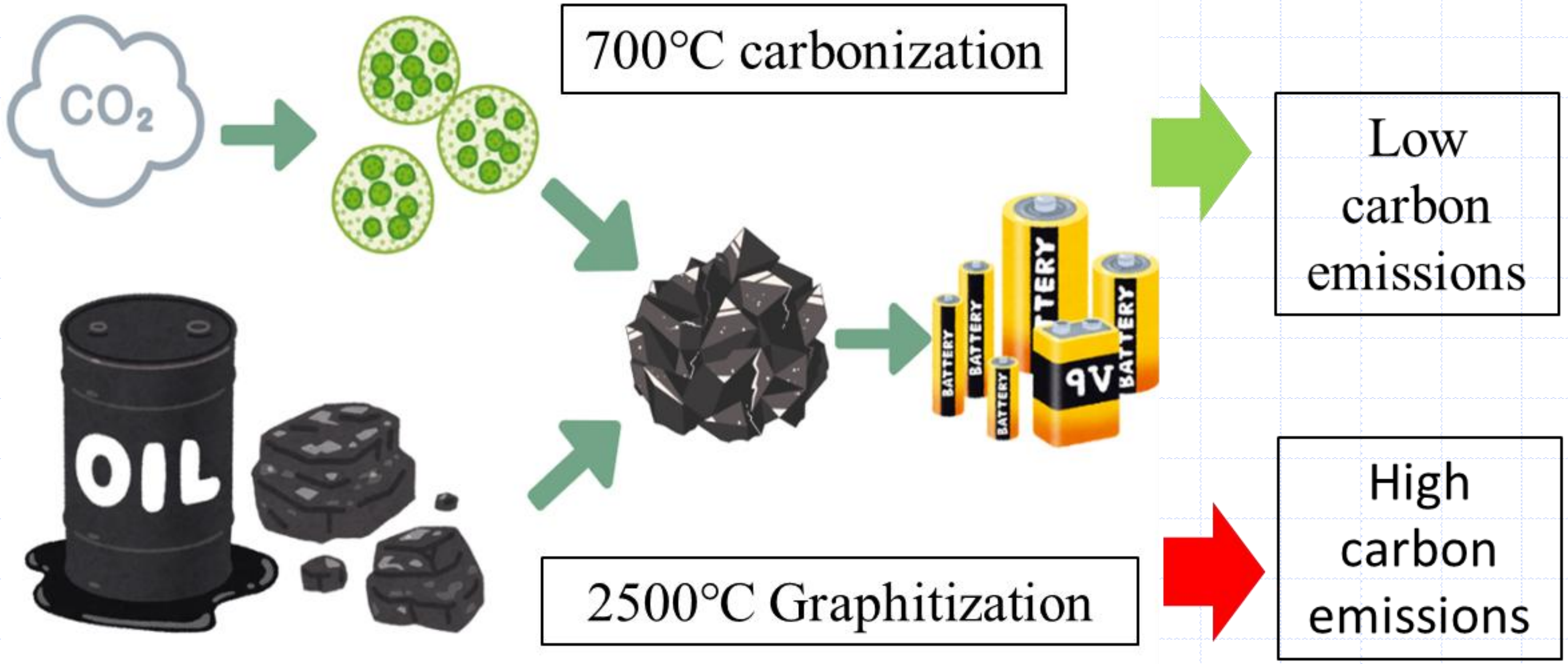
1. When **comparing only** the carbon emissions from the **drying systems**, the thermal convection drying method developed in this subproject can **reduce CO_2 emissions by 95%** compared to freeze-drying.
2. The current global production of microalgae is approximately **10,000 to 40,000 tons**. If the drying method proposed in this project is adopted, it could **reduce carbon emissions by 45,000 to 180,000 tons per year**.





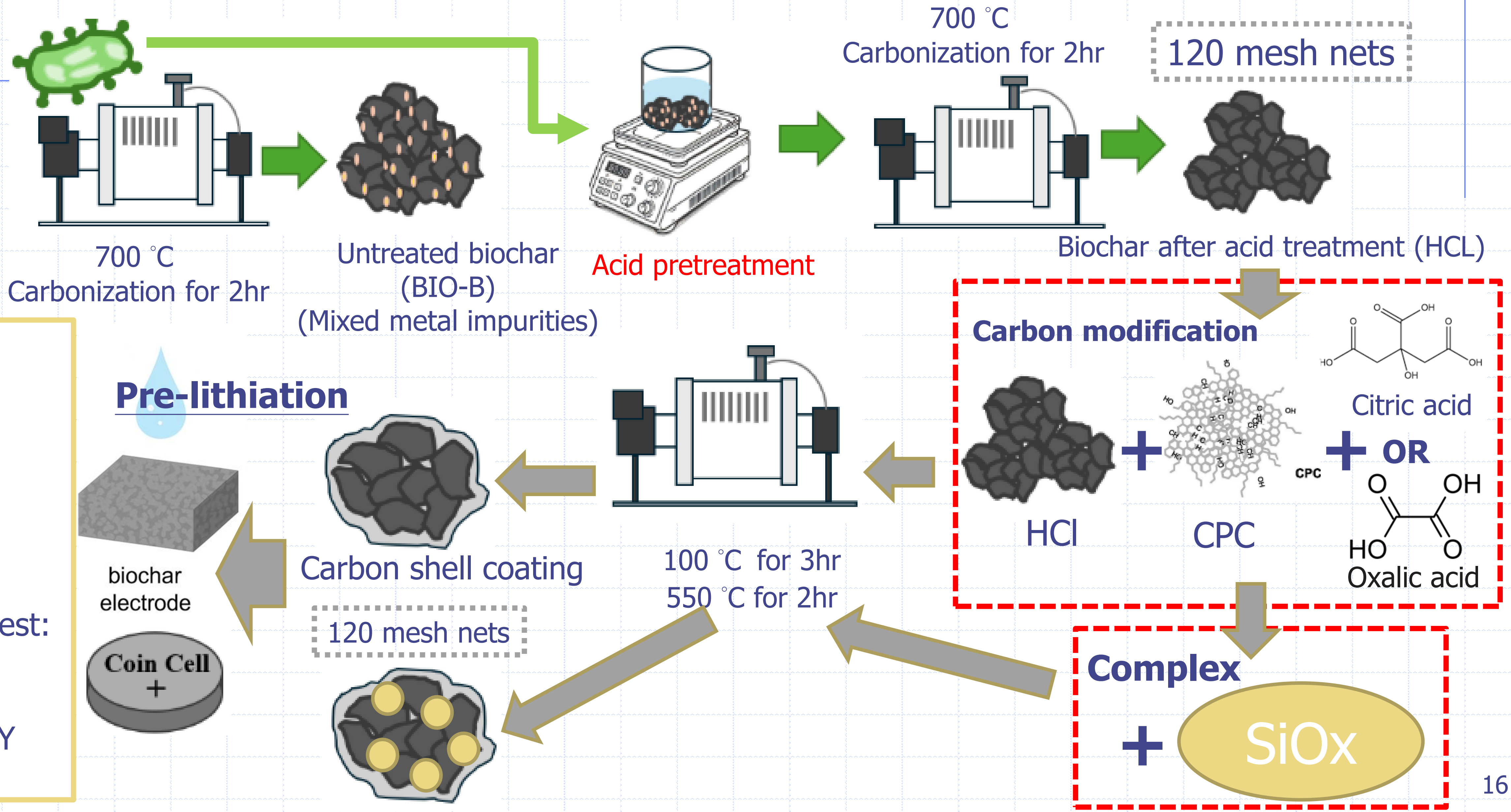
Biochar-based Electrode

The objective is to create **biochar-based anode materials** that combine low carbon emissions with reliable battery performance.

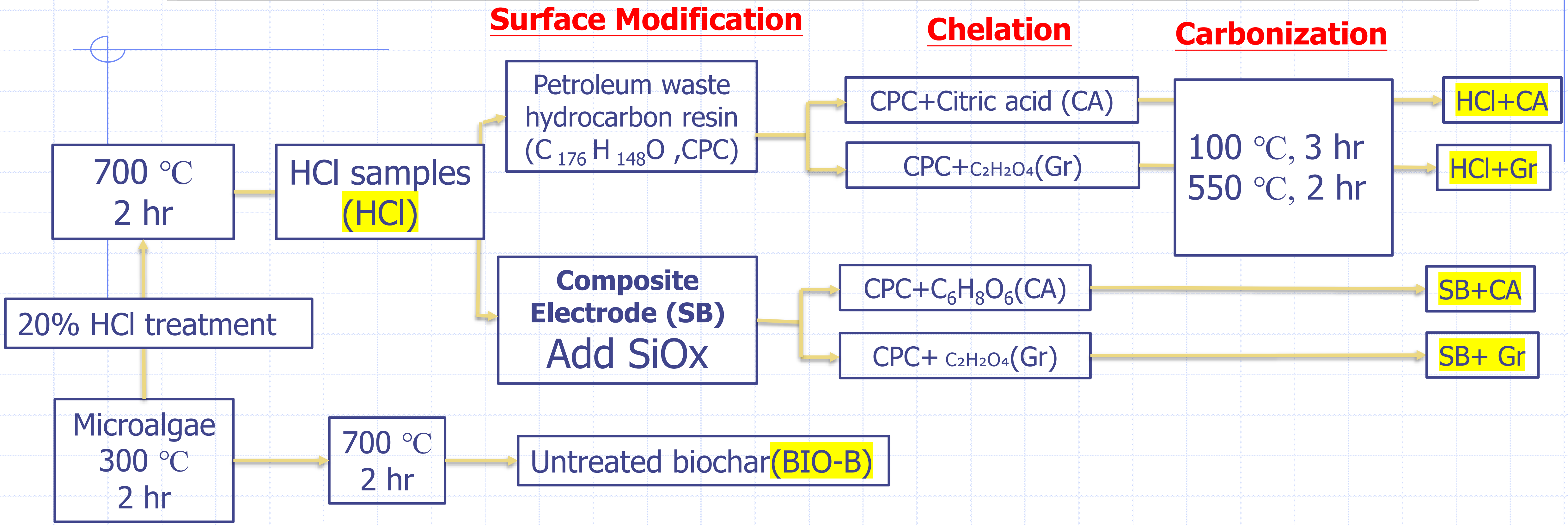


Process and Surface Modification

Material analysis:
SEM
EDS
TEM
XRD
RAMAN
Electrical test:
Formation
EIS
0.1C CYCLY
C-RATE



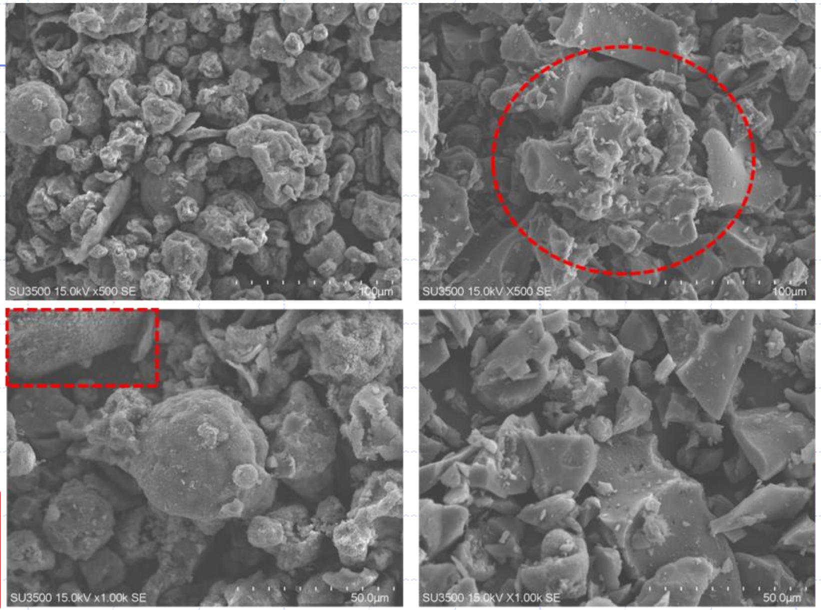
Biochar Surface Modification and Carbonization



\	HCl samples	CPC	Oxalic acid	Citric acid	NMP
HCL+GR	2	1	0.22	X	5
HCL+CA	2	1	X	0.3	5

Composite Electrode(SB)	HCl samples	SiOx	CPC	Oxalic acid	Citric acid	NMP
SB+CA	2	0.22	1.2	X	0.37	5
SB+GR	2	0.22	1.2	0.29	X	5

Impact of Hydrochloric Acid Treatment on Material Properties

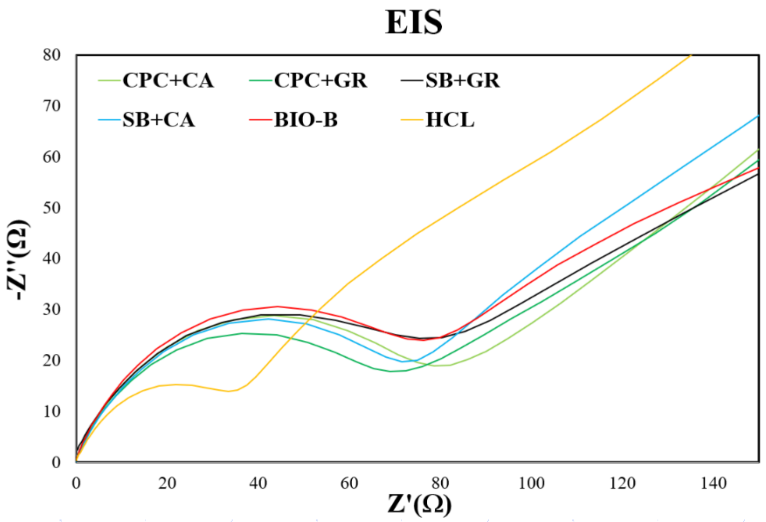


(A)BiO-B sample (B) HCl sample

Surface impurities with visible flocculent deposits were observed.

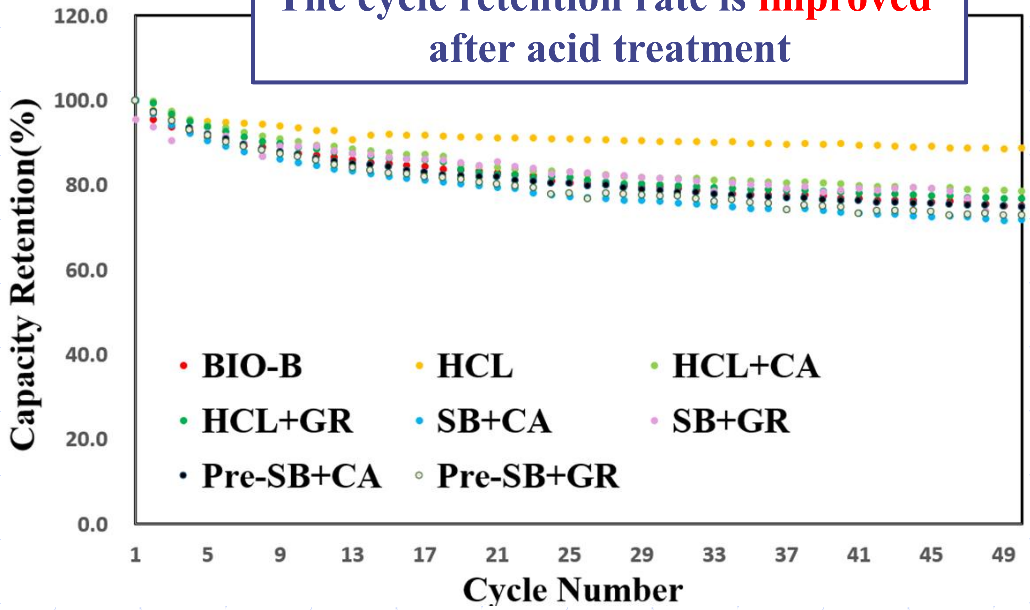
Aggregation after acid treatment

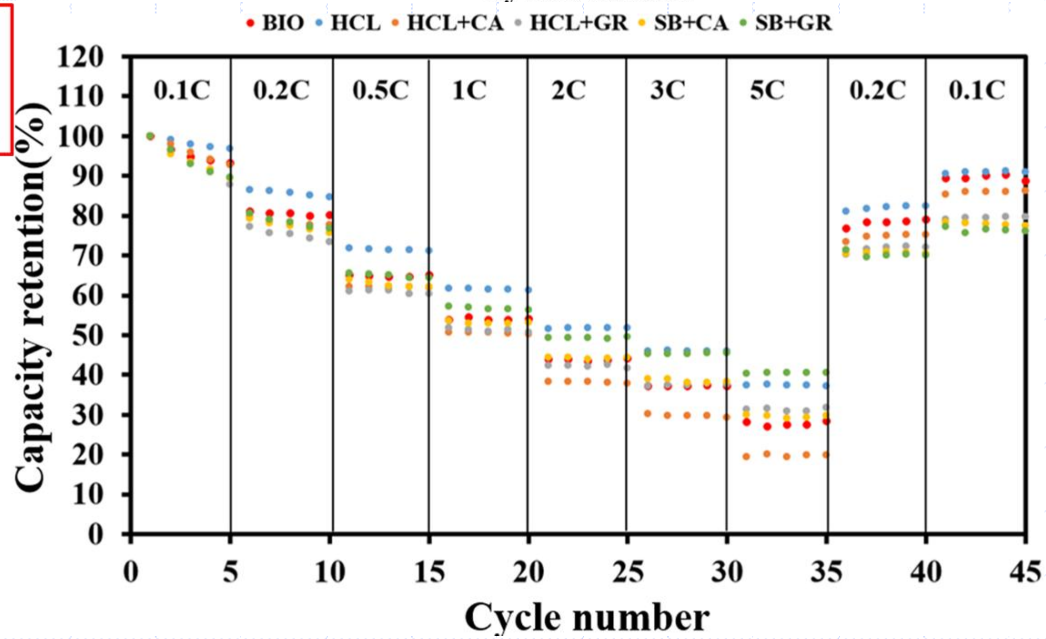
After acid treatment, the surface became smoother with the absence of the original flocculent features.



The impedance is less after acid treatment

The cycle retention rate is improved after acid treatment





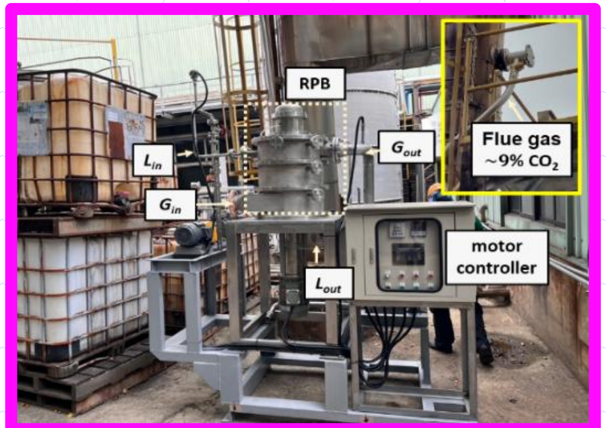
The structural stability was improved after acid treatment

Comparison of Biochar-Based Battery Performance

Source of biochar	Processing	Carbonization temperature	Capacity (mAh/g)	I.C.E.	Current density	50 cycles (mAh/g)	References
Microalgae (This study)	• HCl(20%) • Petroleum waste hydrocarbon resin (CPC) • Citric acid • Oxalic acid • Silicon oxide(SiOx)	700℃ 2hr →550℃ 2hr	489.9681	49%	50mA/g	357.8	This study
Olive pomace	H_3PO_4 (22% wt)	500℃ (1 hr)	288	45%	25mA/g	~260	1
Banana fibers	$ZnCl_2$	800 (1hr)	280	38.7%	90mA/g	~200	2
Aspergillus	• HCl • NaOH	600 (2HR)	143.58	48.9%	1 A/g	~250	3
Plane tree leaves	KOH (2 mol/L)	500、600、700、800 ℃，2 hr	460.4	50.8%	0.05 A/g	~320	4

1. ALOUIZ, Imad, et al. Performance of high-energy storage activated carbon derived from olive pomace biomass as an anode material for sustainable lithium-ion batteries. Resources Chemicals and Materials, 2024.
2. STEPHAN, A. Manuel, et al. Pyrolitic carbon from biomass precursors as anode materials for lithium batteries. Materials Science and Engineering: A, 2006, 430.1-2: 132-137.
3. GU, Runxin, et al. Aspergillus niger fermentation residues application to produce biochar for the anode of lithium-ion batteries. Journal of Environmental Management, 2023, 346: 118985.
4. FENG, Dandan, et al. Biomass derived porous carbon anode materials for lithium-ion batteries with high electrochemical performance. International Journal of Electrochemical Science, 2024, 19.3: 100488.

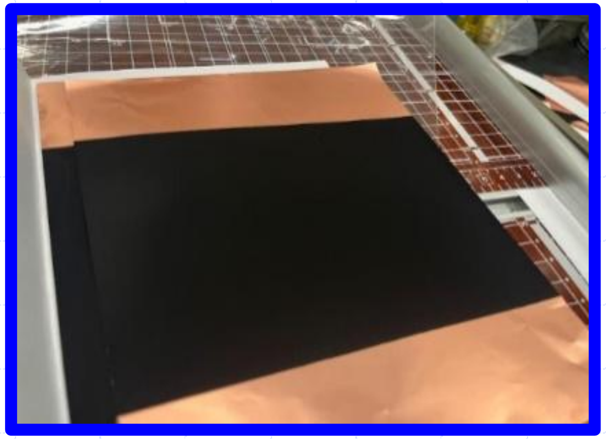
Advanced Sustainable Carbon Technology Development



- Using a CO_2 absorption system operating under ambient temperature and pressure, 100 tons of CO_2 emissions can be captured annually

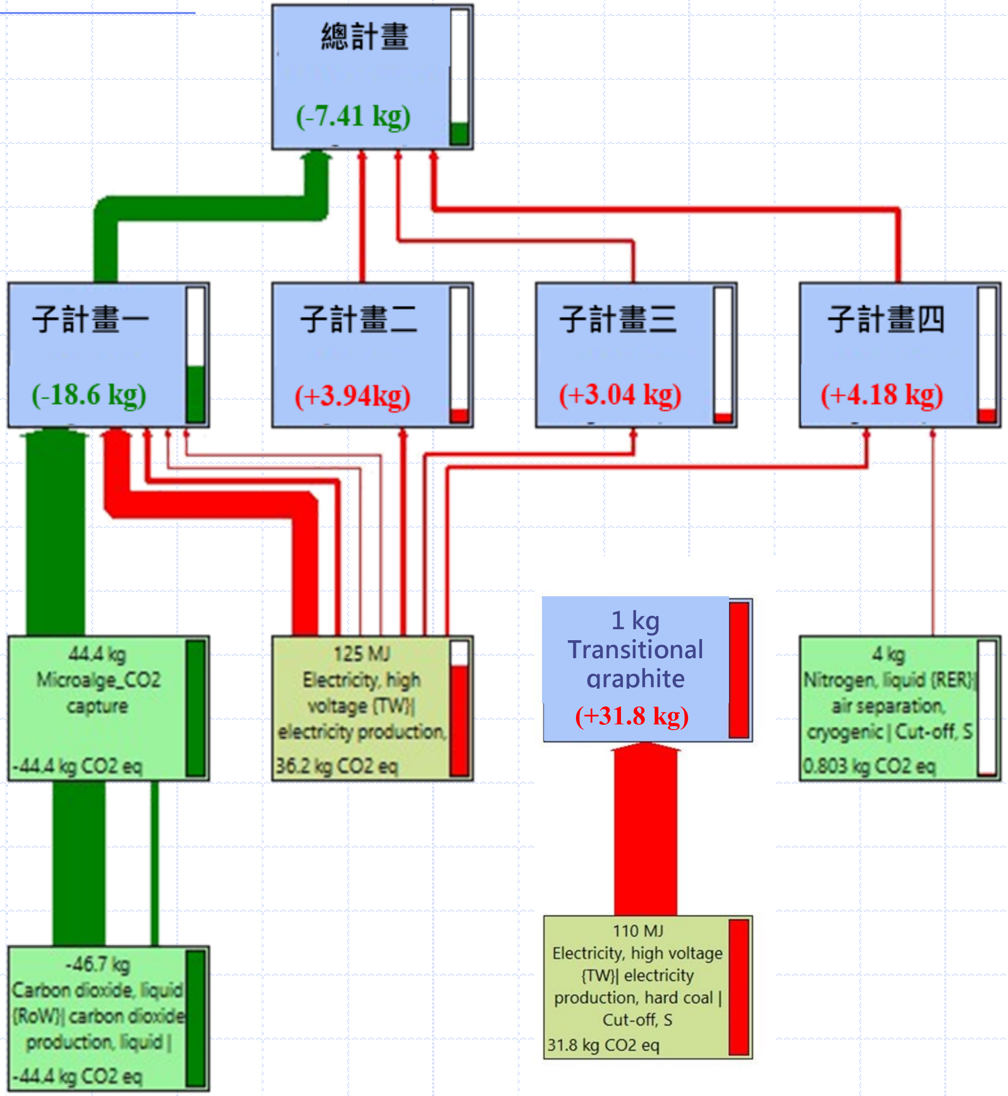
- Using a microalgae carbon-reduction module, 100 tons of CO_2 can be consumed annually to produce 16 tons of microalgae.

- Based on a 55% solid yield, every 16 tons of algal biomass can annually produce 8.8 tons of microalgae biochar



- Using microalgae as the carbon source, 8.8 tons microalgae biochar can annually produce 2.7 tons of lithium carbonate

Life Cycle Assessment (LCA)



Compared to conventional **graphite production** from fossil fuel, 1 kg graphite production from this novel process can reduce **39 kg carbon emissions**.

Integration for Innovation

Thanks for your attention