From Waste to Resources: Multi-Pathway Approaches for Livestock Waste Resource Recovery and Greenhouse Gas Mitigation

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Curriculum Vitae

- 2026~현재 전남대학교 동물자원학부 조교수
- 2025~2025 국립축산과학원 스마트축산환경과 농업연구관
- 2022~2025 한양대학교 자원환경공학과 공학박사
- 2018~2022 세종대학교 환경에너지융합학과 공학박사(수료)
- 2015~2018 전남대학교 동물공학과 농학석사
- 2014~2024 국립축산과학원 축산환경과 농업연구사
- 2008~2015 전남대학교 동물자원학부 농학사

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Sustainable Livestock Waste Valorization through Intergrated Conversion Process

Department of Animal Science
Chonnam National University

Dong-Jun Lee, Ph. D.

Education & Research Careers

Work Experience

Senior researcher, NIAS, RDA (2025.01.~2025.12.)
- Energy recovery from livestock manure (BSFL)
- Biochar production and application

Reseracher, National Institute of Animal Science (NIAS), RDA (2014.08.~2024.12.)
- Thermochemical conversion of livestock manuare for energy recovery (Pyrolysis, Solid fuel)
- Biological treatment of livestock manure (Composting & Liquid fertilization)

Research area

Livestock manure management and resource recovery
- Thermochemical conversion (pyrolysis, solid fuel production)
- Biochar production & utilization
- CO_2 utilization
- Biofuel (Biodiesel)

Project

Institutional research projects on livestock mnuare treatment
- Quality enhancement of cattle manure solid fuel ~ for ash derived from combustion of cattle manure solid fuel + 10 projects (RDA)
- Changes in livestock manure characteristics during resource recovery facility operation (24, KOSPO)
- Development of portable measuring system for compost maturity using gas concentration measurement techniques (21-22, IPET)
- Monitoring of water evaporation from liquid fertilizer storage tanks in swine farms (19, KPPA)

Patent & transfer

11 Patents, 3 case of design trnasfer
- Method and device for calculating moisture content to achieve target lower heating value ('24)
- Method and apparatus for predicting calorific value of cattle manure solid fuel using compositional information of cattle manure ('24)
- Method and apparatus for calculating unit emission factors of livestock manure ('24)

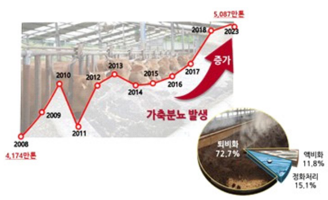
Activities

Advisory activities in livestock environmental field
- Establishment of agro-livestock circular system activation plan ('25~current)
- Joint planning committee work for livestock manure solid fuel ('24~'25)
- Review and advisory committee member for livestock environment status survey ('22~current)
- Livestock manure treatment facility supply project ('19~current)

Research motivation

✓ Changes in the Livestock environment

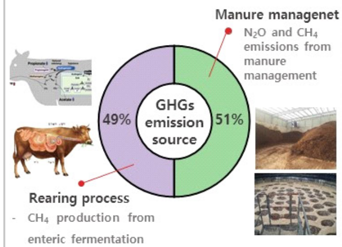
Livestock waste and Environmental burden



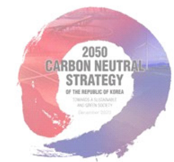
출처: 농식품부 국내 가축분뇨 발생량(2023)

- Livestock manure generation
  - 50.8 million tones in 2023
- Current status
  - 84.5% (Compost 72.7%+Liquid 11.8%)

Livestock-derived GHGs emissions



- Nutrient loading   * ( )은 저감량
  - Nitrogen 301 (169), Phosphorus 61 thousand (23)
- GHGs emission('21)
  - Manure managenet: 5.4 million tons CO_2-eq (25%)



Waste reduction & management

- Thermochemical process (Pyrolysis, Solid fuel)
- Waste upcycing (Insect biomass)

Reduction of carbon emission

- Carbon sequestration (biochar)
- Carbon-to-utilization

Research motivation

Combustion (Heat): over 1000 °C

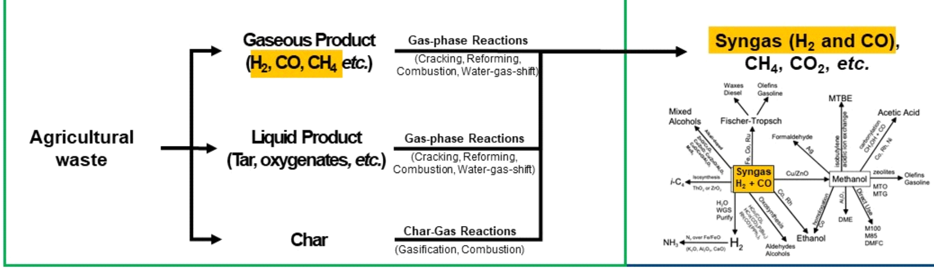
Complete oxidation — CO_2, H_2O, and Heat

Gasification: 700 – 1500 °C

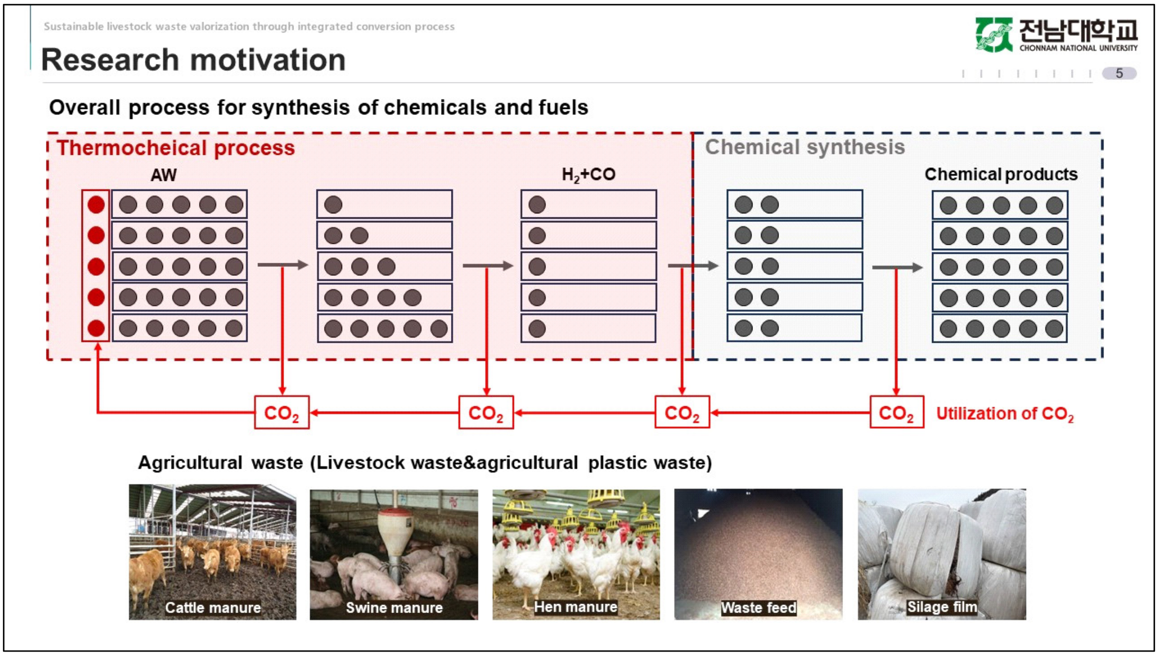
Partial oxidants (O_2, air, steam, etc.)

Pyrolysis: 300 – 700 °C

Absence of oxidant



- (Gasification) Energy intensive process
- (Pyrolysis) Intermediate step of gasification → lower energy input
- **Research objective : Pyrolysis temperature range + strategies to increase syngas yield**



Sustainable livestock waste valorization through integrated conversion process
Research motivation
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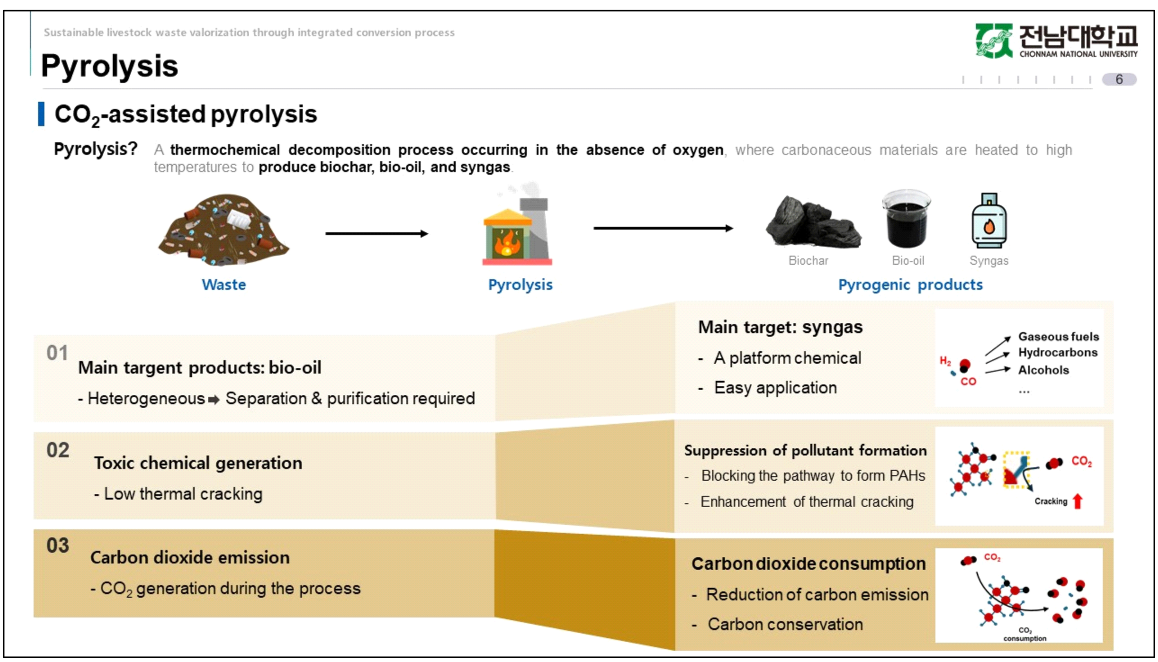
Overall process for synthesis of chemicals and fuels
Thermocheical process
Chemical synthesis
AW
H_2+CO
Chemical products
CO_2
CO_2
CO_2
CO_2
Utilization of CO_2
Agricultural waste (Livestock waste&agricultural plastic waste)
Cattle manure
Swine manure
Hen manure
Waste feed
Silage film



Sustainable livestock waste valorization through integrated conversion process
Pyrolysis
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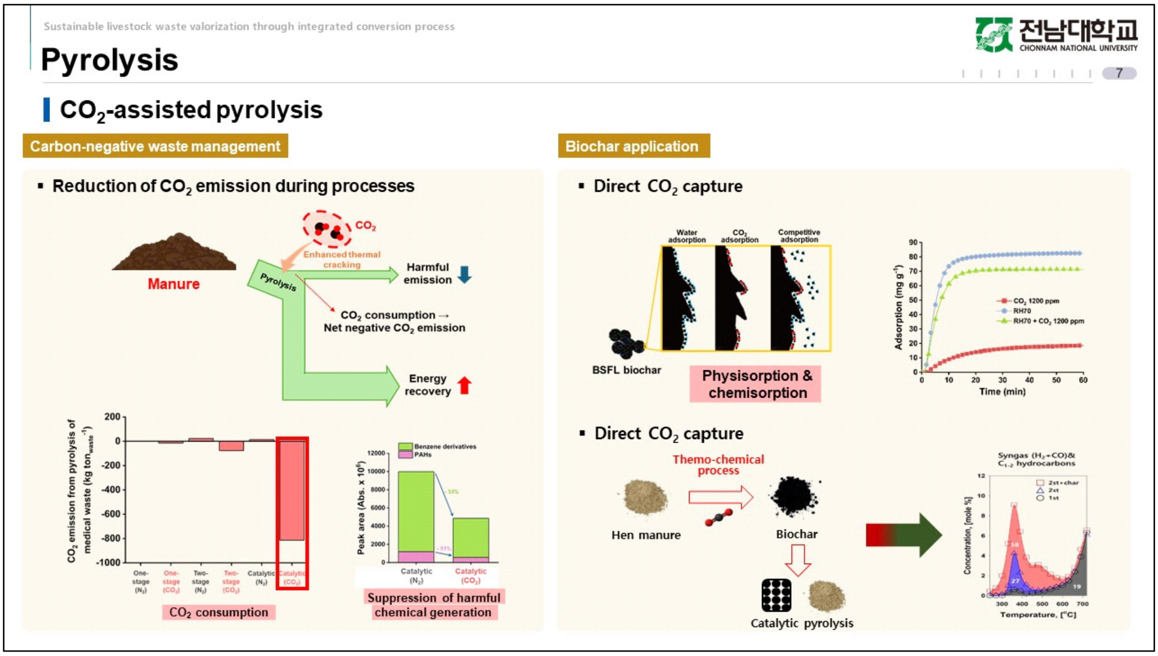
CO_2-assisted pyrolysis
Pyrolysis? A thermochemical decomposition process occurring in the absence of oxygen, where carbonaceous materials are heated to high temperatures to produce biochar, bio-oil, and syngas.
Waste
Pyrolysis
Biochar
Bio-oil
Syngas
Pyrogenic products
01
Main targent products: bio-oil
- Heterogeneous ➡ Separation & purification required
Main target: syngas
- A platform chemical
- Easy application
H_2
CO
Gaseous fuels
Hydrocarbons
Alcohols
...
02
Toxic chemical generation
- Low thermal cracking
Suppression of pollutant formation
- Blocking the pathway to form PAHs
- Enhancement of thermal cracking
CO_2
Cracking
03
Carbon dioxide emission
- CO_2 generation during the process
Carbon dioxide consumption
- Reduction of carbon emission
- Carbon conservation
CO_2
CO_2 consumption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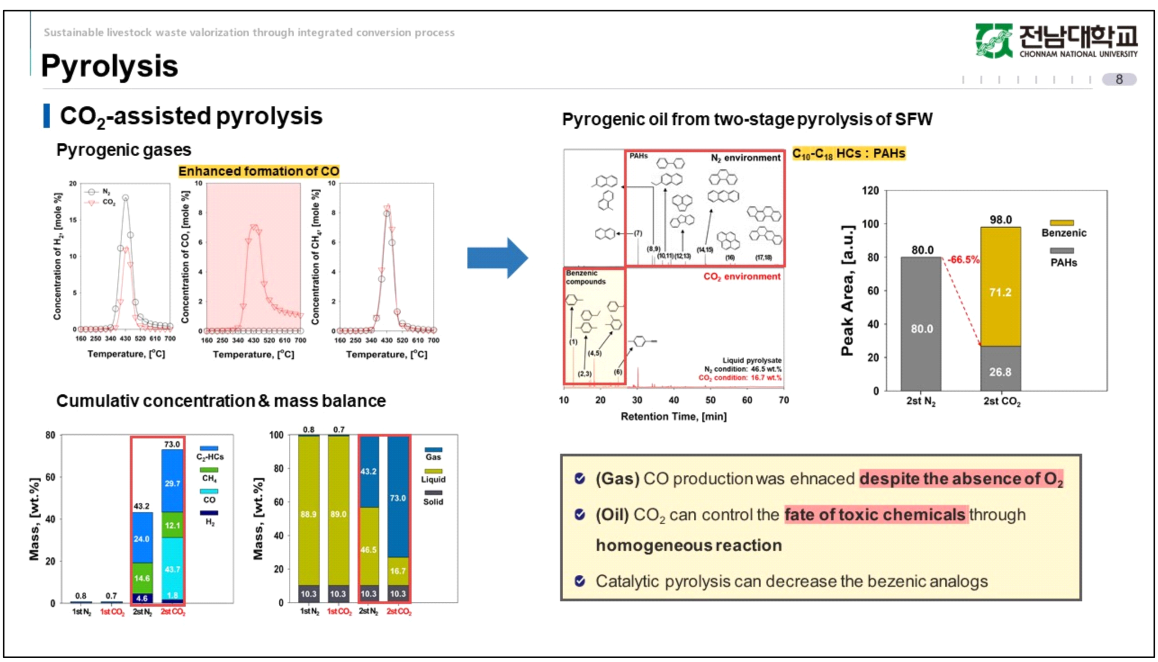
CO2-assisted pyrolysis
Carbon-negative waste management
Reduction of CO2 emission during processes
Manure
CO2
Enhanced thermal cracking
Pyrolysis
Harmful emission
CO2 consumption → Net negative CO2 emission
Energy recovery
CO2 consumption
Suppression of harmful chemical generation
Biochar application
Direct CO2 capture
Water adsorption
CO2 adsorption
Competitive adsorption
BSFL biochar
Physisorption & chemisorption
Time (min)
Direct CO2 capture
Thermo-chemical process
Hen manure
Biochar
Catalytic pyrolysis
Temperature, [°C]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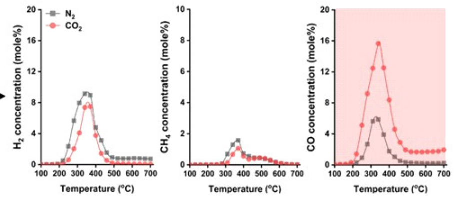
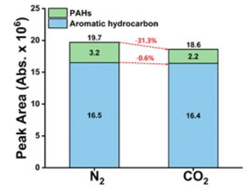
CO2-assisted pyrolysis
Pyrogenic gases
Enhanced formation of CO
Temperature, [°C]
Cumulativ concentration & mass balance
Pyrogenic oil from two-stage pyrolysis of SFW
N2 environment
CO2 environment
Retention Time, [min]
C10-C18 HCs : PAHs
Peak Area, [a.u.]
Benzenic
PAHs
(Gas) CO production was ehnaced despite the absence of O2
(Oil) CO2 can control the fate of toxic chemicals through homogeneous reaction
Catalytic pyrolysis can decrease the bezenic analogs

Pyrolysis

Livestock carcasses (LSC)



Enhanced formation of gases



Decrease in aromatic analogues

High densitiy of livestock farming

- Antibiotic residues
- Green house gases
- Confirmed that **CO_2-assisted pyrolysis can be utilized as a greenhouse gas mitigation technology**

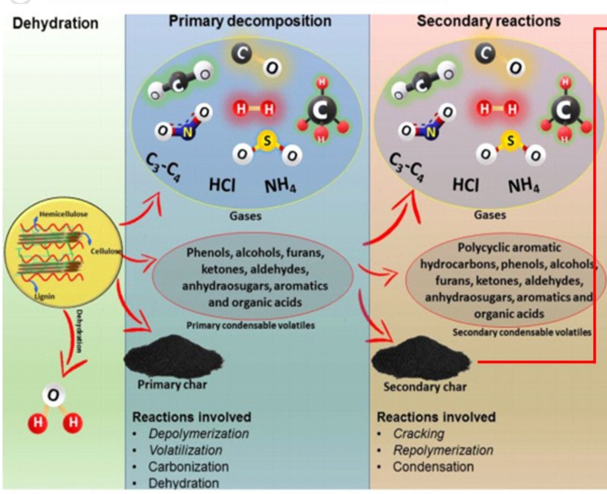
Table 1

Carbon footprint and energy recovery potential of various LSC treatment systems (assuming high H_2 selectivity ($\geq$96 %) via rWGSR).

	Content	Landfill	Pyrolysis	
			N_2	CO_2
(1)	**CO_2 emission, [g CO_2-eq g^{-1} LSC]**	–	–	–
	CH_4 emission	0.55	0.03	0.02
	CO_2 emission	1.06	0.08	–
	ΣCO_2-eq emission [g CO_2-eq g^{-1} LSC]	16.48	0.86	0.48
(2)	**CO_2 reduction [g CO_2-eq g^{-1} LSC]**			
	Biochar carbon sequestration	–	0.34	0.36
	CO_2 utilisation	–	–	0.54
	ΣCO_2-eq reduction [g CO_2-eq g^{-1} LSC]	–	0.34	0.90
(3)	**Carbon footprint [g CO_2-eq g^{-1} LSC]**	16.48	0.52	−0.42

Biochar

✓ Thermochemcial conversion of biocahr

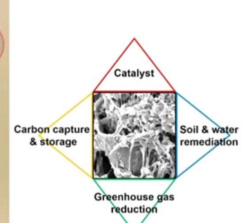


IPCC 2019 GL

: Solid material generated by heating biomass to a temperature **in excess of 350 ℃** under conditions of controlled and **limited oxidant concentration** to prevent combustion

EBC (European biochar celtificate)

: Biochar is **a porous, carbonaceous material** that is produced by pyrolysis of biomass and is applied in such a way that the contained carbon remains stored as a long-term C sink or replaces fossil carbon in industrial manufacturing.



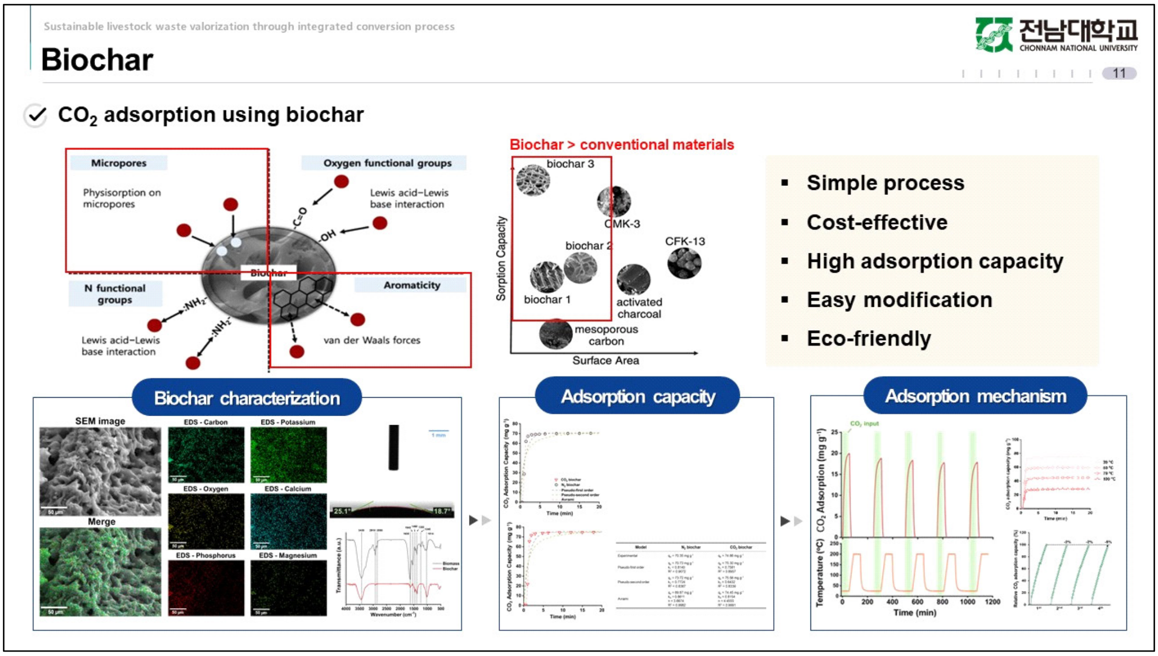
Biochar properties

- Carbon-Negative
- Porous meterial

Biochar application

- Direct CO_2 capture
- Soil amendment

* Source) Industrial biochar systems for atmospheric carbon removal: a review (2021, Environmental chemistry letters)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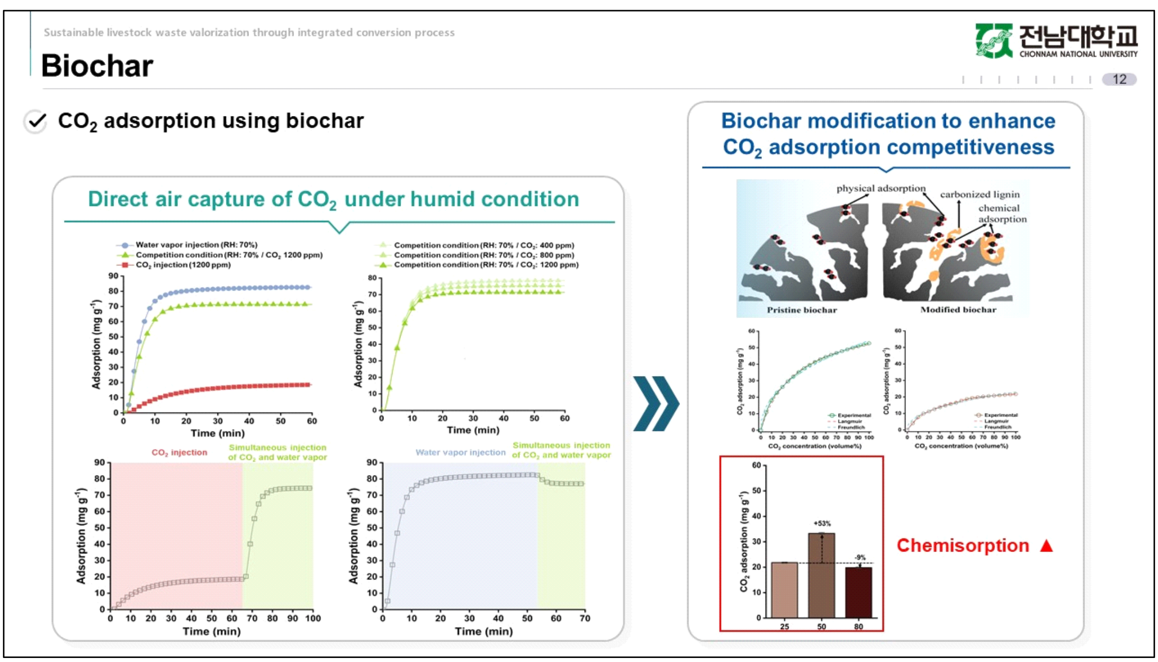
CO2 adsorption using biochar
Micropores
Physisorption on micropores
Oxygen functional groups
Lewis acid–Lewis base interaction
N functional groups
Lewis acid–Lewis base interaction
Aromaticity
van der Waals forces
Biochar
Biochar > conventional materials
biochar 3
CMK-3
CFK-13
biochar 2
biochar 1
activated charcoal
mesoporous carbon
Sorption Capacity
Surface Area
Simple process
Cost-effective
High adsorption capacity
Easy modification
Eco-friendly
Biochar characterization
SEM image
Merge
EDS - Carbon
EDS - Potassium
EDS - Oxygen
EDS - Calcium
EDS - Phosphorus
EDS - Magnesium
Adsorption capacity
Adsorption mechanism
Time (min)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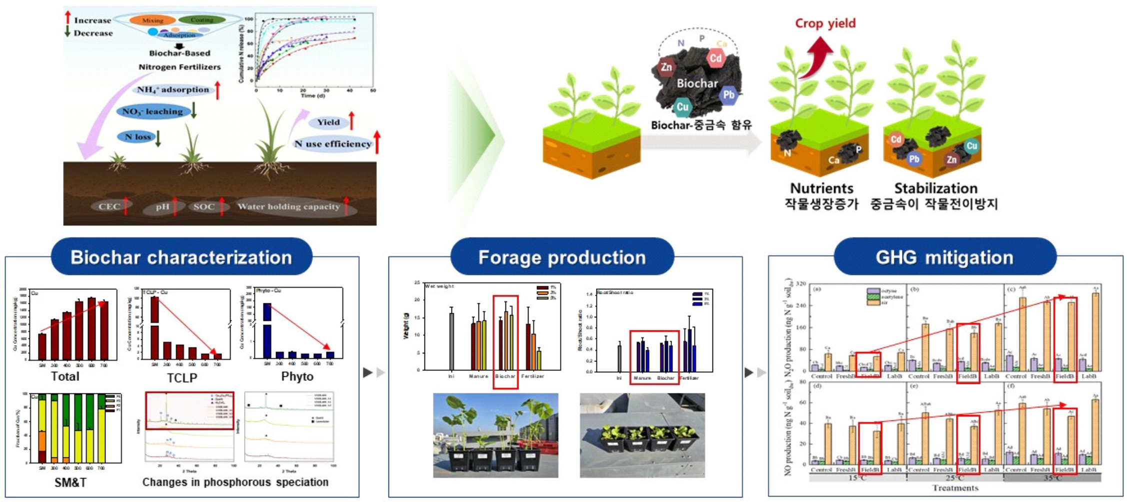
CO2 adsorption using biochar
Direct air capture of CO2 under humid condition
Water vapor injection (RH: 70%)
Competition condition (RH: 70% / CO2 1200 ppm)
CO2 injection (1200 ppm)
Competition condition (RH: 70% / CO2: 400 ppm)
Competition condition (RH: 70% / CO2: 800 ppm)
Competition condition (RH: 70% / CO2: 1200 ppm)
Adsorption (mg g-1)
Time (min)
CO2 injection
Simultaneous injection of CO2 and water vapor
Water vapor injection
Biochar modification to enhance CO2 adsorption competitiveness
physical adsorption
carbonized lignin
chemical adsorption
Pristine biochar
Modified biochar
CO2 concentration (volume%)
CO2 adsorption (mg g-1)
+53%
-9%
Chemisorption ▲

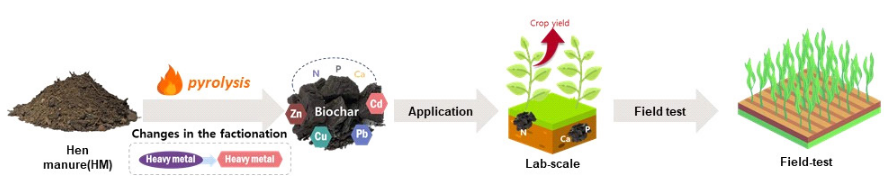
Biochar

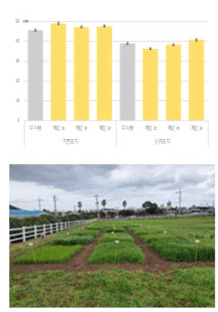
✓ Forage production using biochar



Biochar

✓ Forage test: Expansion to filed test

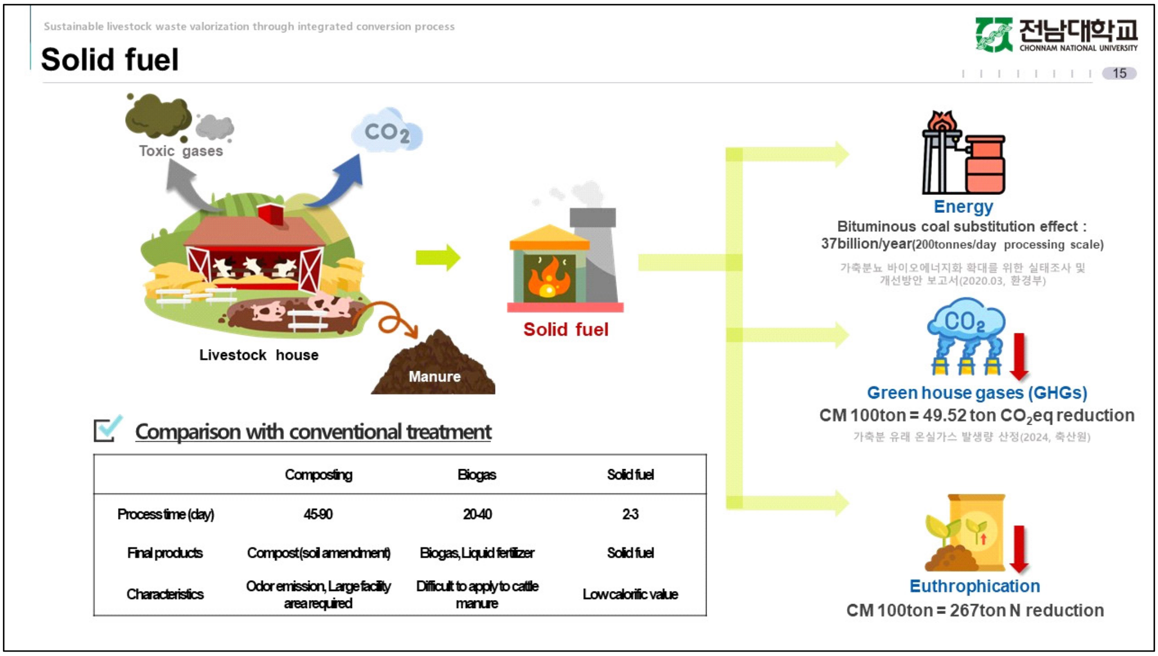




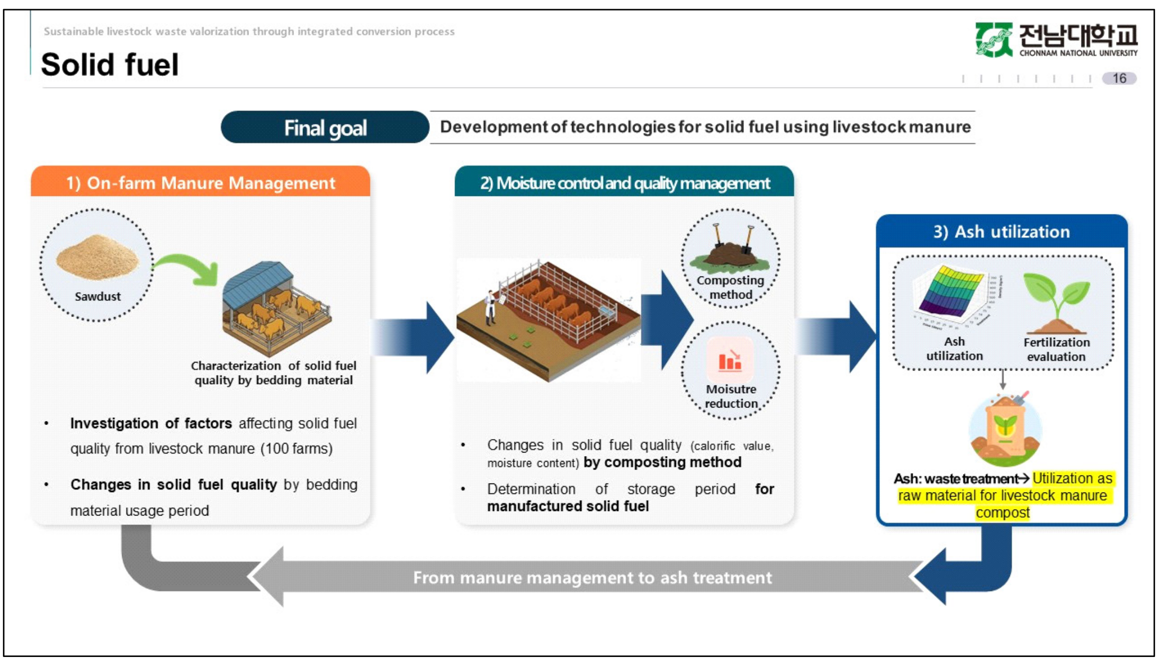
Biochar	Grassland
▪ High pH (Ca, Mg) ▪ Porous structure ▪ Cation exchange capacity (CEC) ▪ SOC stabilization	▪ Acidified soils ▪ Low OM

From the field test (Tall fescue)..

- Hen manure (HM) with 2.9% N showed clear potential as a soil fertilizer.
- The optimal application rate for forage yield was 6 ton ha[-1]

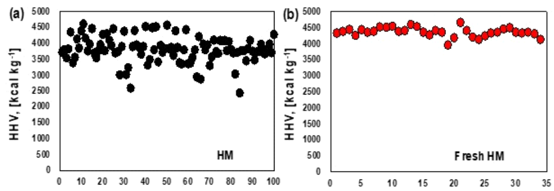


	Composting	Biogas	Solid fuel
Process time (day)	45-90	20-40	2-3
Final products	Compost(soil amendment)	Biogas, Liquid fertilizer	Solid fuel
Characteristics	Odor emission, Large facility area required	Difficult to apply to cattle manure	Low calorific value

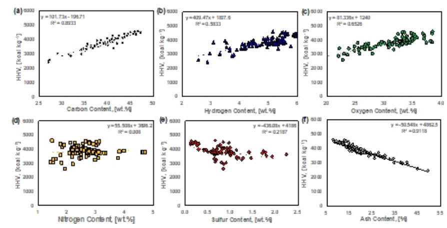


Solid fuel

1. Manure Investigation of fators affecting solid fuel quality from livestock manure (100 farms)



Survey of calorific value of cattle manure (CM) from domestic livestock farms

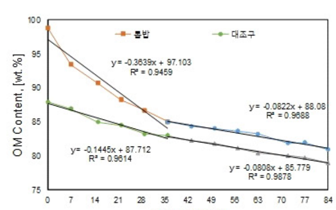


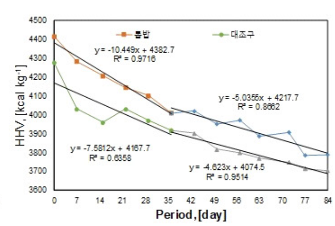
Relationship between organic matter/elemental composition and calorific value of cattle manure

- Solid fuel standard: 3,000kcal/kg (HHV: 4,200kcal/kg)
- Survey results: 3,802.1 ± 407.5 kcal/kg (100 farms) vs **4,383.2 ± 140.9kcal/kg (fresh CM)**
  - * manure excretion timing, bulking agent utilization, compost recycling
- Key factor: Organic matter (R^2): **0.9118 → 50.5 kcal/kg per 1% organic matter**

Solid fuel

2. Storage period Determination of the storage period of livestock manure





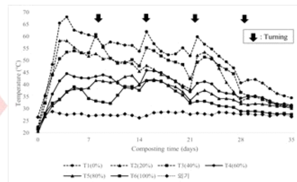
- (Problems) Aerobic fermentation during storage in barns → reduction in heating value
- Evaluation of heating value changes in livestock manure during storage
- **Optimal storage period: 90days**

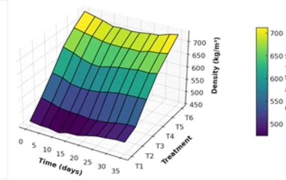
Solid fuel

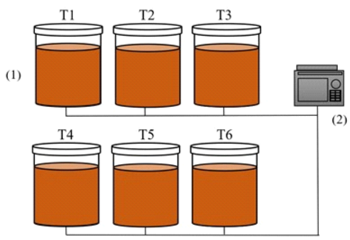
3. Ash Effect of ash level on composting performance

Ash addition level and sawdust replacement by treatment

	Composting treatment setup (kg)				Addition level (c/a)
	compost (a)	Bulking agent (b)	ash (c)	Total (a+b+c)	
T1 (0%)	87.2	21.5	0.0	108.7	**0%**
T2 (20%)	87.2	16.5	4.1	107.8	**5%**
T3 (40%)	87.2	11.9	7.9	107.0	**10%**
T4 (60%)	87.2	7.6	11.5	106.3	**14%**
T5 (80%)	87.2	3.7	14.8	105.6	**18%**
T6 (100%)	87.2	0.0	17.8	105.0	**22%**







Experimental setup

- Temperature: Only **T1 and T2** met the **USDA composting safety standard** (above 55 °C, 3 days or more)
- (Densitity) High ash content → Increase densitiy → **Porosity ↓+ Fermentation ↓**
- (EA) Increase in mixing ratio → Organic matter ↓ → **Composting inhibition**

* Carbon content: T1: 40.0, T2: 35.0……..T5:21.7, **T6:20.0**

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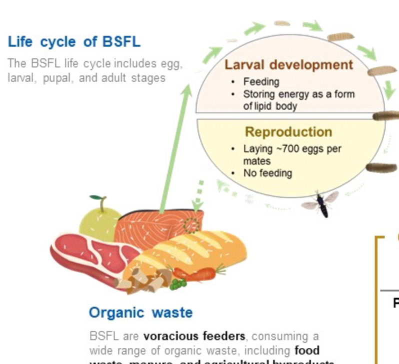
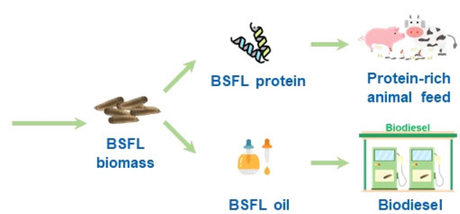
Waste Upcycing

✓ Entomoremediation

- BSFL are considered a sustainable bioconversion technology for waste management and resource recovery, as they rapidly decompose organic waste and convert it into protein-rich larval biomass and organic fertilizer.



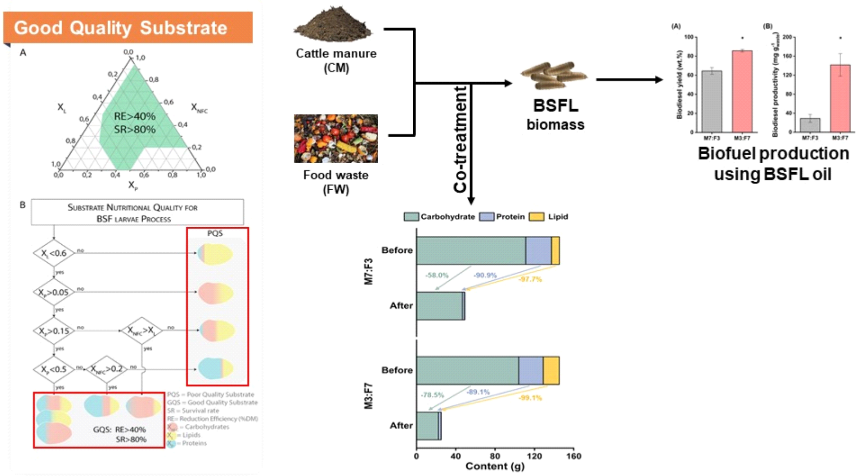


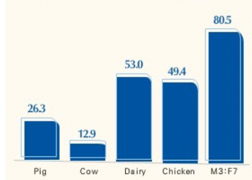
Comparison with conventional methods

	Composting	Anaerobic digestion (AD)	BSFL cultivation
Processing time	Weeks to Months	Weeks	**Days to Weeks**
Products	Compost (soil conditioner)	Biogas (energy) Digestate (fertilizer)	**Animal feed Biodiesel (energy) Frass (fertilizer)**
Greenhouse gas emission	Medium	High	**Low**

Waste Upcycling

✓ Insect biomass (BSFL)





Compared to composting,

- **The processing time** was reduced by 73 % (90→ 24days)

Co-feeding strategy

- **384.6 g kg^{-1},** suppressing previous research by **more than 3 times compared to single feeding**

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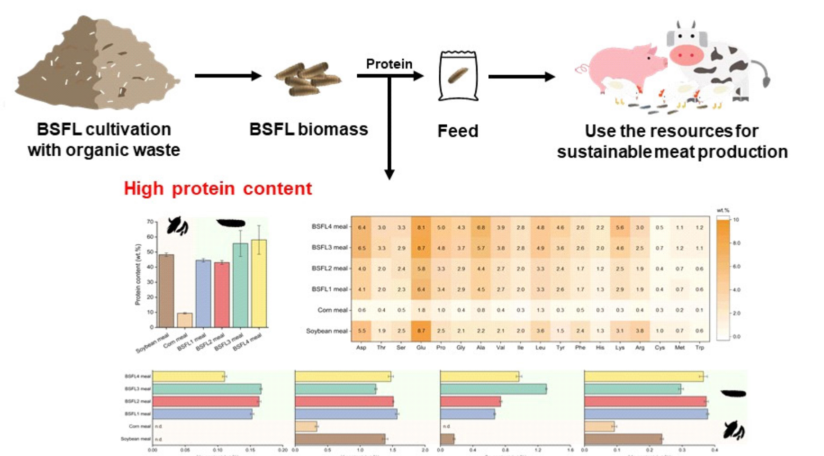
Waste Upcycling

✓ Insect biomass (BSFL)



Broiler
- Leucin, Valine, Isoleucine

Swine
- Lysine, methionine, Cysteine

Compared to soybean meal,

- **The amino acid compositions of BSFL were similar to Soybean meal**
- **BSFL-derived proteins have high potential as a livestock feed protein source**
- **BSFL: 42,471 - 48,345 kg $_{protein}$ ha^{-1} y^{-1} > Soybean: 1,174 kg ha^{-1} y^{-1}**

Future Research Topic

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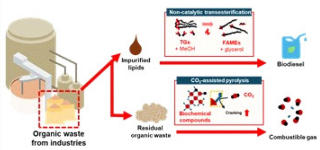
Integrated platform

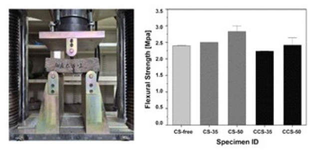
Integrated thermal and biological treatment for zero waste



- (before) single-process treatment
- **(Improved)** Integrated application of pyrolsysis + biodiesel conversion → **Enhanced energy recovery**

Waste valorization

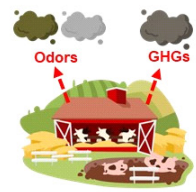
Development of practical valorization strategies for biochar and ash



- (Problem) limited utilization of biochar and ash (high salinity and heavy metals)
- **(solution) Cross-industry valorization (e.g., paving blocks)**

Emission control

Livestock odor monitoring and mitigation technology



- Emission factor development by livestock management strategies (composting, slurry)
- **Meseaurement method (adsorption tube) + mitigation technologies (Photocatalyst)**

Enhancement of livestock environment through multidisciplinary approaches

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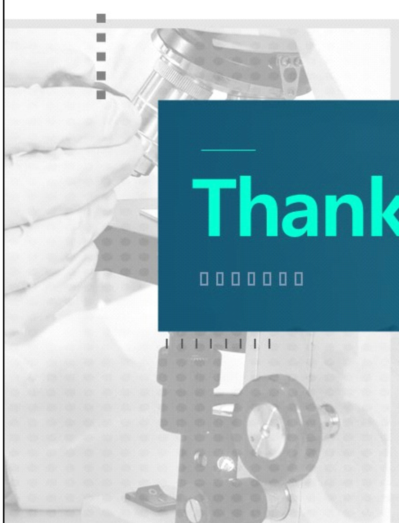

Thank you

Sustainable Livestock Waste Valorization through Intergrated Conversion Process

THANK YOU